PB83-258335

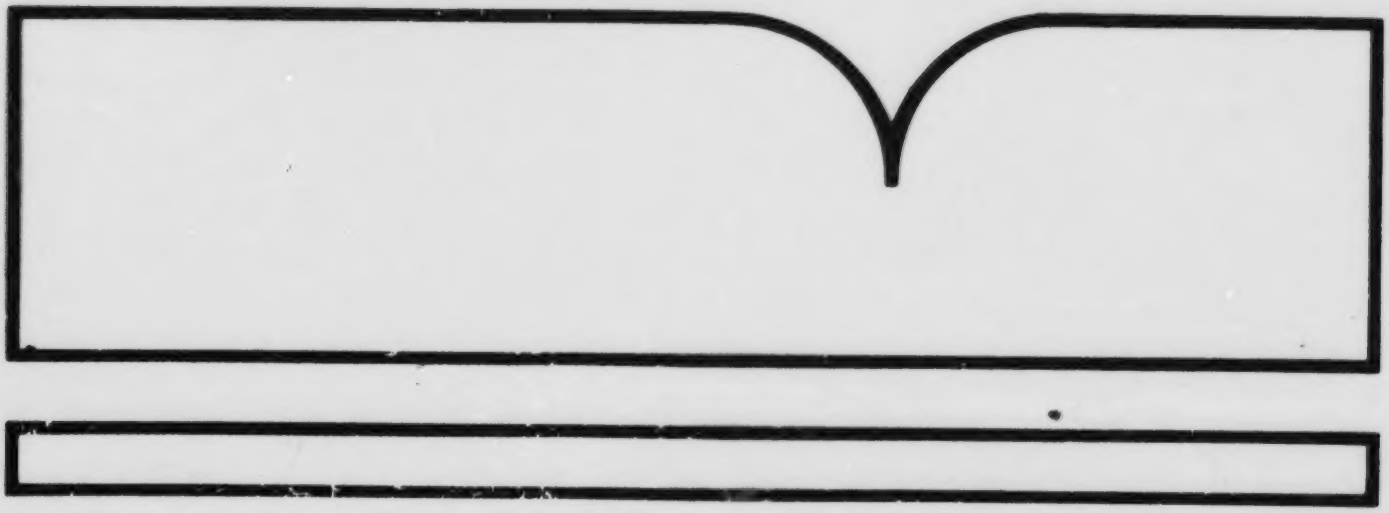
Benefits Analysis of Alternative Secondary National Ambient Air Quality Standards for Sulfur Dioxide and Total Suspended Particulates. Volume 1

Mathtech, Inc., Princeton, NJ

Prepared for

Environmental Protection Agency
Research Triangle Park, NC

Aug 82



U.S. Department of Commerce
National Technical Information Service
NTIS

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
450/5-83-001A		PB83 258335

4. TITLE AND SUBTITLE	5. REPORT DATE
Benefit Analysis of Alternative Secondary National Ambient Air Quality Standards for Sulfur Dioxide and Total Suspended Particulates	August 1982
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Ernest H. Manuel, Jr. Kathleen M. Brennan Robert L. Horst, Jr.	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Mathtech, Inc. P.O. Box 2392 Princeton, NJ 08540	10. PROGRAM ELEMENT NO. DU11A2A
	11. CONTRACT/GRANT NO. 68-02-3392
12. SPONSORING AGENCY NAME AND ADDRESS U.S. Environmental Protection Agency Office of Air Quality Planning and Standards Research Triangle Park, NC 27711	13. TYPE OF REPORT AND PERIOD COVERED Final Report
	14. SPONSORING AGENCY CODE OAQPS

15. SUPPLEMENTARY NOTES

Project Officer: Allen C. Basala

16. ABSTRACT

This study was initiated by EPA's Office of Air Quality Planning and Standards as part of its review of the current secondary standards for sulfur dioxide (SO_2) and total suspended particulates (TSP). The study has drawn heavily upon new data and research advances from the past decade or so, and considerably expands the information available about the economic benefits of selected air pollution control regulations.

The theoretical base for the analysis is a series of models structured to simulate optimizing behavior by members of society in markets where air quality has an influence. Groups of these members of society are referred to as "economic sectors." The four sectors analyzed in this study are: 1) Household, 2) Agricultural, 3) Manufacturing, and 4) Electric Utilities.

Consideration of optimizing behavior allows for the possibility of differing responses to air pollution. This reduces the potential for biased estimates and also allows inferences consistent with the willingness-to-pay criterion.

Benefits were calculated for the current and an alternative (24-hour averaging time) SO_2 secondary standard and for the current TSP secondary standard. Subsequent to a public peer review meeting, additional analyses were undertaken to assess the validity of the benefit estimates.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Economic Sectors Benefits Analyses Optimizing Behavior Secondary National Ambient Air Quality Standards Air Pollution, SO_2 and TSP		

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
Release Unlimited	Unclassified	125
	20. SECURITY CLASS *(This page)*	22. PRICE
	Unclassified	

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

B1 - CONTROL NUMBER: U255707
B4 - ACCESSION NUMBER: PB83-258335
B3 - COLLECTION CODE: 5
B6 - MANAGEMENT CODE: QS
B7 - PROCESS ACTNG CD: 80 B7A-REGISTRATION FEE: 00000
B8 - PRODUCT MANAGER: H
B9 - RECEIPT TYPE: 1 B9A-LOAN DUE OUT:
B10- TRANSACTION: TN B10A-DUPE/PRIOR/SUPER:
B12- RETURNS: 0 B12A-RETURN DATE:
B13- PROCESSING: 0
B14- PAT. POTENTIAL: 0
B17- FORM/PRICE: 12111
B18- ANNOUNCE: 1101
B19- PUBLICATION-1: u8326 B20- PUBLICATION-2:
B21- LIMITATION: 0
B23- PC BIN: 219
B24- STOCK: 0010 B24A-STOCK TYPE CODES: D
B25- PAGES/SHEETS: 00121
B26- PC PRICE CODE: A06
B27- DOMESTIC PRICE: 0000000 B28- FOREIGN PRICE: 0000000
B29- ACTION CODES: SS
B33- MN PRICE CODE: A01
B34- DOMESTIC PRICE: 0000000 B35- FOREIGN PRICE: 0000000
B36- ACTION CODES: MA
B37- RELEASABILITY CD: C
B38- MF PRINT: A
B39- ADDITIONAL INFO: y
B40- PRINT PC: n
B41- PC DUE: n
B42- SOURCE ORDER: n
B42A-GENERATE RDP: 0
B42B-SUPPLIER SRC CD:
@43B)Part of a 6 volume set. @@@
@@@
@@@

PB83-253335

United States
Environmental Protection
Agency

Office of Air Quality
Planning and Standards
Research Triangle Park NC 27711

EPA-450/5-83-001a
August 1982

Air

EPA

Benefit Analysis of Alternative Secondary National Ambient Air Quality Standards for Sulfur Dioxide and Total Suspended Particulates

Volume I

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

FINAL ANALYSIS

BENEFITS ANALYSIS OF ALTERNATIVE SECONDARY NATIONAL AMBIENT AIR QUALITY STANDARDS FOR SULFUR DIOXIDE AND TOTAL SUSPENDED PARTICULATES

VOLUME I

Benefits Analysis Program
Economic Analysis Branch
Strategies and Air Standards Division
Office of Air Quality Planning and Standards

U.S. Environmental Protection Agency

Research Triangle Park
North Carolina 27711

August 1982

FINAL ANALYSIS

BENEFITS ANALYSIS OF ALTERNATIVE SECONDARY NATIONAL AMBIENT AIR QUALITY STANDARDS FOR SULFUR DIOXIDE AND TOTAL SUSPENDED PARTICULATES

By:

Ernest H. Manuel, Jr.
Robert L. Horst, Jr.
Kathleen M. Brennan
William N. Lanen
Marcus C. Duff
Judith K. Tapiero

With the Assistance of:

Richard M. Adams
David S. Brookshire
Thomas D. Crocker
Ralph C. d'Arge
A. Myrick Freeman, III
Shelby D. Gerking
Edwin S. Mills
William D. Schulze

MATHTECH, Inc.
P.O. Box 2392
Princeton, New Jersey 08540

EPA Contract Number 68-02-3392

Project Officer:
Allen C. Basala
Economic Analysis Branch
Strategies and Air Standards Division
Office of Air Quality Planning and Standards
U.S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711

August 1982

PREFACE

This report was prepared for the U.S. Environmental Protection Agency by MATHTECH, Inc. The report is organized into six volumes containing a total of 14 sections as follows:

Volume I

- Section 1: Executive Summary
- Section 2: Theory, Methods and Organization
- Section 3: Air Quality and Meteorological Data

Volume II

- Section 4: Household Sector
- Section 5: Residential Property Market
- Section 6: Labor Services Market

Volume III

- Section 7: Manufacturing Sector
- Section 8: Electric Utility Sector

Volume IV

- Section 9: Agricultural Sector

Volume V

- Section 10: Extrapolations
- Section 11: Bibliography

Volume VI

- Section 12: Summary of the Public Meeting
- Section 13: Analysis of Pollutant Correlations
- Section 14: Summary of Manufacturing Sector Review

The analysis and conclusions presented in this report are those of the authors and should not be interpreted as necessarily reflecting the official policies of the U.S. Environmental Protection Agency.

ACKNOWLEDGMENTS

This report and the underlying analyses profited considerably from the efforts of Allen Basala, who served as EPA Project Officer, and V. Kerry Smith, who served as a reviewer for EPA. Allen provided the initiative and on-going support to conduct an applied benefits analysis. Kerry's technical insights and suggestions are reflected in nearly every section of the report.

James Bain and Tom Walton of EPA, and Jan Laarman and Ray Palmquist, who served as reviewers for EPA, also contributed substantially to individual report sections through their advice and comments during the course of the project. Also providing helpful comments and assistance were Don Gillette, Fred Haynie, Neil Frank and Larry Zaragosa, all with EPA.

Several other members of the Mathtech staff contributed to the project during various stages of the work. They included Robert J. Anderson, Jr., Neil Swan, John Keith, Donald Wise, Yaw Ansu, Gary Labovich, and Janet Stotsky.

The production of the report was ably managed by Carol Rossell, whose patience remained intact through countless drafts and deadlines. Carol was assisted by Sally Webb, Gail Gay, and Deborah Piantoni.

Finally, we extend our appreciation to the many dozens of individuals, too numerous to list here, who provided advice, suggestions, and data during the course of the project.

CONTENTS

1. EXECUTIVE SUMMARY

Background 1-1

Study Scope and Objectives 1-3

Theoretical Base 1-4
Empirical Base 1-6
Efficient Use of Resources 1-6
Reliability Checks in the Analysis 1-7
Public Meeting 1-7

General Assumptions Underlying the Benefits Estimates 1-9

Air Quality Scenarios 1-9
Economic Scenario 1-10

Summary of Estimated Benefits 1-12

Scope of the Estimates 1-12
Benefits of the Current SO_2 Secondary Standard . 1-14
Benefits for the Alternative SO_2 Secondary Standard 1-15
Benefits for the Current TSP Secondary Standard 1-16
Geographic Distribution of Benefits 1-17

Organization of the Report 1-18

References 1-19

2. THEORY, METHODS AND ORGANIZATION

Introduction 2-1

Physical Effects of SO_2 and TSP 2-1
Behavioral Responses to Air Pollution 2-3
Economic Benefits of Improved Air Quality 2-4
Overview of Later Subsections 2-7

CONTENTS (continued)

2. THEORY, METHODS AND ORGANIZATION (continued)

The Definition of Economic Benefits 2-10

Willingness to Pay 2-11
Consumers' Surplus 2-14
Producers' Surplus 2-15
Benefits of a Particular Action or Event 2-17
Measuring Benefits by Cost Savings 2-18
Alternative Measures of Economic Benefits 2-20
Measuring Benefits in Intermediate Markets 2-22
Summary 2-24

Indirect-Market Approaches for Estimating Air Quality Benefits 2-24

Air Pollution Effects on Firms 2-26
Air Pollution Effects on Households 2-28
Other Indirect-Market Approaches 2-35
Air Quality Benefits Not Observable in Market Behavior 2-37
Aggregation and Coverage of Benefits Categories 2-39

Organization of the Study and Report 2-41

Organizing Framework 2-41
Selection of Sectors 2-43
Coverage of Sectors 2-49
Validation of Results 2-52

References 2-56

3. AIR QUALITY AND METEOROLOGICAL DATA

Introduction 3-1

Air Quality Data 3-1

Total Suspended Particulates (TSP) 3-7
Sulfur Dioxide (SO_2) 3-15
Other Pollutants 3-27

Meteorological Data 3-27

References 3-31

FIGURES

Number		Page
2-1.	An illustration of the calculation of total willingness-to-pay	2-14
2-2.	Illustration of the calculation of consumers' surplus	2-15
2-3.	Producers' surplus	2-16
2-4.	Consumers' and producers' surplus	2-17
2-5.	Change in economic surplus	2-19
2-6.	Change in consumers' and producers' surplus due to an improvement in air quality from S to S'	2-28
2-7.	Change in consumers' and producers' surplus due to an improvement in air quality from S to S'	2-30
2-8.	Benefits of an improvement in ambient air quality ...	2-33
2-9.	Organizing framework for the study	2-42

TABLES

Number		Page
1-1.	Scope of the Study	1-8
1-2.	Current National Ambient Air Quality Standards for SO_2 and TSP	1-11
1-3.	Coverage of Economic Activity in Each Sector	1-13
1-4.	Estimated Benefits in Sectors Analyzed for Current SO_2 Secondary Standard	1-14
1-5.	Estimated Benefits in Sectors Analyzed for Alternative SO_2 Secondary Standard	1-16
1-6.	Estimated Benefits in Sectors Analyzed for Current TSP Secondary Standard	1-17
2-1.	Coverage of Economic Activity in Each Sector	2-50
3-1.	National Ambient Air Quality Standards for Particulate Matter	3-9
3-2.	National Ambient Air Quality standards for Sulfur Dioxide	3-16
3-3.	An Alternative Set of Ambient Air Quality Standards for Sulfur Dioxide	3-17

SECTION 1

EXECUTIVE SUMMARY

SECTION 1

EXECUTIVE SUMMARY

BACKGROUND

Traditionally, the U.S. Environmental Protection Agency has emphasized the evaluation of the negative economic consequences of alternative air pollution control regulations. Hence, while control costs, price increases, and output declines have been examined for the candidate alternatives, the beneficial economic aspects of the regulations have been largely ignored. This is in spite of the acknowledged fact that information about the economic benefits would provide decision makers with a more balanced view of the consequences of regulation. Ideally, the improved balance would result in regulations which are more economically efficient.

The failure to include comprehensive and rigorous treatment of the economic benefits of environmental policies has not been without a supporting rationale. Economic benefits have been difficult to measure due to a wide variety of methodological, data, and ethical problems. Some of the more important problems that have prevailed included: the nonmarket nature of the clean air commodity; the need to separate health and welfare benefits; the need to consider how the affected populations can reduce the effects of pollution through their

own actions (i.e., "substitution possibilities"); and the distributional considerations of any accrued benefits.

This study was initiated by EPA's Office of Air Quality Planning and Standards in order to allow broader consideration of potential economic benefits. It was commissioned following a determination that research and technical advances in the 1970's had reached the point where measurement of selected economic benefits was feasible. These advances included:

- The development of more reliable air pollution measurement techniques and a broader network of air pollution monitoring sites.
- Advances in economic theory that clarified the requirements for measuring the economic effects of nonmarketed commodities such as clean air.
- Developments in physical effects research that identified more of the mechanisms and determinants of air pollution damage.
- Advances in economic theory and data that provided new techniques for understanding consumer and producer economic behavior.
- New types of computer software that made practical the use of advanced statistical techniques.

This study has thus drawn heavily upon new data and research advances from the past decade or so. We believe the study considerably expands the information available about the economic benefits of selected air pollution control regulations. The details of the study are presented in the report sections which follow.

STUDY SCOPE AND OBJECTIVES

Under authority provided by the Clean Air Act of 1970, as amended (1), the U.S. Environmental Protection Agency (EPA) has promulgated regulations that require the attainment of certain standards of ambient air quality throughout the country. One set of standards has been established at levels designed to protect human health; these are referred to as the Primary National Ambient Air Quality Standards (PNAAQS). A second set of standards has been established at levels to protect the public welfare (e.g., other items of value such as vegetation and materials); the latter are referred to as the Secondary National Ambient Air Quality Standards (SNAAQS). The Clean Air Act also requires the EPA to review these standards on a periodic basis.

This study was initiated by EPA's Office of Air Quality Planning and Standards as part of its review of the current secondary standards for sulfur dioxide (SO_2) and total suspended particulates (TSP). The primary goal of this study was to estimate selected non-health benefits which would result from achieving alternate SO_2 and TSP secondary standards. The rationale for excluding the human health benefits was that the primary standards presumably protect human health with an adequate margin of safety. Hence the health effects associated with the more restrictive secondary standards were expected to be small or nonexistent.

Other benefits not covered in this study are those associated with reduced acidic deposition and visibility improvement. Acidic deposition effects were not considered because the role of ambient SO_2 in acidic deposition has not been clearly identified. Visibility effects were omitted because fine particulate concentrations rather than TSP are believed to be more directly associated with visual quality impacts.

The scope of the analysis was further refined to meet the following four objectives:

- A sound theoretical and empirical base for estimating benefits.
- Efficient use of available project resources.
- Incorporation of reliability checks into the analysis.
- Peer review of study results.

Theoretical Base

The correct starting point for a benefits analysis is a consideration of the value which society places on improved air quality. Economists generally agree that attempts to measure this value should be based on individuals' own valuations, as evidenced by their "willingness-to-pay" for improved air quality. For conventional types of goods and services, evidence of willingness-to-pay can be found by analyzing supply and demand conditions in the markets where those goods and services are traded. Unfortunately, however, no such market

for air quality exists. In the absence of a market for air quality, we are unable to observe directly the price, and thus the willingness-to-pay, for improvements in air quality.

An alternative approach is to observe how air quality influences the behavior of the members of society in related markets. Although members of society may not directly interact in a market for air quality, they do interact in markets for many other commodities and services potentially affected by air quality. As one example, we know from field studies that sulfur oxides cause corrosion damage to certain types of steel structures used by industrial firms. Unless the various responses to corrosion (e.g., maintenance and repair) are costless, the effect of air pollution will be to increase the costs and lower the productivity of these firms. Thus, by observing the extent to which costs (or productivity) vary in areas with differing air quality, while taking into account other factors that influence cost, one can infer the economic effects of air pollution on these firms.

The theoretical base for this benefits analysis is a series of models structured to simulate optimizing behavior by members of society in markets where air quality has an indirect influence. We refer to groups of these members of society as "economic sectors". Consideration of optimizing behavior allows for the possibility of differing responses to air pollution. This reduces the potential for

biased estimates and also allows inferences consistent with the willingness-to-pay criterion.

Empirical Base

The development of a sound empirical base for the study involved exploration, identification, evaluation, and, where necessary, augmentation of economic and aerometric data bases. This entailed extensive discussions with representatives of the Bureau of Economic Analysis, Bureau of Labor Statistics, Bureau of the Census, the Monitoring and Data Analysis Division of EPA, and other public and private organizations. As a result of these procedures and discussions, the quality and limits of the economic and aerometric data were better understood.

Efficient Use of Resources

In April of 1980, a document was distributed describing the various economic sectors which could benefit from reduced SO_2 and TSP concentrations and the detailed plans for estimating benefits in each of these sectors. In May of 1980, a meeting was held to discuss the document and to assess the likelihood of successfully estimating benefits in each economic sector. Over 60 persons representing several agencies and disciplines attended the May meeting and provided valuable feedback. As a result, selected economic sectors offering the greatest prognosis for success were identified.

The selected sectors included the household, manufacturing, electric utilities, and agricultural sectors. Within each of these sectors, statistical models were constructed to estimate some of the benefits. These estimates were then extrapolated geographically and categorically to broaden the scope of the study. The overall scope of the study is summarized in Table 1-1.

Reliability Checks in the Analysis

The sector approach is significantly different from many of the dose-response analysis techniques which have been traditionally used to estimate benefits. Consequently, several validation checks were built into the study. These included assessments of model form, data inputs, and model performance. Not only environmental economists and econometricians, but also plant pathologists, materials effects engineers, and air quality data specialists provided suggestions regarding these checks. This doesn't mean our approach or the analysis results will satisfy all. However, we have recognized at the outset the multidisciplinary nature of benefits analysis and accounted for it in model design, input data selection, and interpretation of results.

Public Meeting

In July of 1981, a public meeting was held to review a draft version of this report. An announcement concerning the meeting was made in the Federal Register to encourage public attendance and

TABLE 1-1. SCOPE OF THE STUDY

Benefits estimated from statistical models*	Benefits estimated by extrapolation**	Benefits not estimated
Household sector in 24 metropolitan areas	All other households	Visibility and climate effects; costs to landlords
Six manufacturing industries	27 related manufacturing industries	Effects on other manufacturing industries
Electric power generation	Electric power transmission and distribution	Effects on other utility industries
Soybean and cotton production	--	Other animal and vegetation damage
--	--	Effects on governmental, commercial and institutional sectors

* Results reported in Sections 4 through 9 of the report.

** Results reported in Section 10 of the report.

comments. A panel of experts in environmental benefits analysis was also assembled to critically discuss the report at the meeting. Comments from the panel and audience were generally favorable. Following the meeting, various revisions were made to the analysis and this final version of the report was prepared. Two additional plausibility checks were also undertaken at the suggestion of the panel. The findings of the plausibility checks did not appreciably change the original conclusions of the study. A summary of the public meeting and the results of the two additional plausibility checks are included in a new volume of the study (Volume VI).

GENERAL ASSUMPTIONS UNDERLYING THE BENEFITS ESTIMATES

Air Quality Scenarios

The estimates reported in this study represent the benefits of enforcing compliance with secondary standards (SNAAQS) for SO_2 and TSP, as compared to a situation in which only the primary standards (PNAAQS) are enforced. The basic idea, then, is one of calculating the benefits of improving air quality from the level of the primary standard to the level of the secondary standard. There are certain definitional problems in describing this scenario, however, because of the different averaging times used in the primary and secondary standards.*

---

* Averaging time refers to the period of time over which the pollution measurements are averaged.

As shown in Table 1-2, the current standards for SO_2 and TSP are stated in terms of several different averaging times, and in the case of SO_2, there is no primary standard at the averaging time used in the secondary standard. As discussed in Section 3, there are computational procedures which allow approximate conversions to be made between pollution measurements at different averaging times. These techniques were used in the case of SO_2 to establish an equivalent 24-hour secondary standard. Benefits for SO_2 were then calculated for two different scenarios -- one based on the 24-hour equivalent of the current 3-hour secondary standard, and one based on an alternative 24-hour secondary standard. Both sets of benefits estimates are reported in the next section. In the case of TSP, the estimate of benefits is based on the 24-hour averaging time since there is a primary standard corresponding to the secondary standard at that averaging time. For both SO_2 and TSP, compliance with the primary standard is assumed to occur by 1985 and with the secondary standard by 1987.

Economic Scenario

The benefits estimates reported for each sector are based on detailed economic scenarios specific to each sector. The details of these scenarios can be found in later sections of the report. All of the sector estimates, however, incorporate the same three-part calculation. First, the benefits in each year after 1985 are calculated. Time horizons of 50 years or more are used in each sector. Second, all annual values are then converted to 1980 dollars. Third, the

TABLE 1-2. CURRENT NATIONAL AMBIENT AIR QUALITY STANDARDS FOR SO_2 AND TSP

Pollutant and averaging time	Air quality standard ($\mu g/m^3$)	
	Primary	Secondary
Sulfur dioxide		
Annual arithmetic mean	80	--
Maximum 3-hour concentration*	--	1,300
Maximum 24-hour concentration*	365	--
Total suspended particulates		
Annual geometric mean	75	--
Maximum 24-hour concentration*	260	150

* Not to be exceeded more than once per year.

Source: Reference (2).

annual benefits in 1980 dollars are then converted to a discounted present value in 1980, using a (real) discount rate of 10 percent.* The benefits numbers reported are thus discounted present values in 1980, stated in 1980 dollars.

SUMMARY OF ESTIMATED BENEFITS

Scope of the Estimates

The economic sectors considered in this study, as described previously, do not include the full range of sectors in the economy. The specific coverage of sectors is identified in Table 1-3. The top half of the table identifies the final demand sectors in the economy; the bottom half shows the producing sectors. The first and second columns in the table identify the specific sectors and the percent of economic activity accounted for by each sector. The third column indicates the percent of each sector covered by the basic statistical analysis in each sector. For example, the basic analysis in the household sector covered 24 major metropolitan areas and a subset of total consumption expenditures. This represented approximately 17 percent of total activity in the household sector. Through extrapolation of the results for the basic analysis, coverage of this sector was expanded to about 45 to 55 percent of the household sector, as shown in the fourth column.

---

* Estimates using discount rates of 2 and 4 percent were also developed and are reported in the individual sector reports.

TABLE 1-3. COVERAGE OF ECONOMIC ACTIVITY IN EACH SECTOR

Final demand sector	Percent of final demand	Percent coverage	
		Basic analysis	Basic plus extrapolation
Households*	63.5	17	45-55
Government	20.5	0	0
Other	16.0	0	0
Totals	100.0	11**	29-35**

Producing sector	Percent of GNP	Percent coverage	
		Basic analysis	Basic plus extrapolation
Agriculture, forestry and fisheries	3.1	2-15	2-15
Mining and construction	7.1	0	0
Manufacturing	23.9	4-8	25-30
Transportation, communication and utilities	9.0	8-11	15-20
Commercial and services	43.6	0	0
Government and other	13.3	0	0
Totals	100.0	2-3**	7-9**

* Goods and services consumed by individuals and certain nonprofit institutions. Includes rental of dwellings but not purchases of dwellings. The latter are included with "other".

** Weighted average coverage.

Source: Estimates of final demand and GNP shares are from U.S. Department of Commerce, Bureau of Economic Analysis. Survey of Current Business. July 1979. Tables 1.1 and 6.1.

It is important to note that this study does not provide complete coverage of all possible sectors. Nor does it include consideration of effects such as impacts on climate or the ecosystem. In this respect, the benefits reported in the study are conservative estimates of the benefits of the secondary ambient air quality standards.

Benefits of the Current SO_2 Secondary Standard

The estimated benefits for the current SO_2 secondary standard are shown in Table 1-4. As indicated previously, these are discounted

TABLE 1-4. ESTIMATED BENEFITS IN SECTORS ANALYZED, FOR CURRENT SO_2 SECONDARY STANDARD* (discounted present values for 1980 in millions of 1980 dollars)**

Sector	Basic analysis+	Basic analysis with extrapolation
Households	--	2.0
Agricultural	0.2	0.2
Manufacturing	--	6.4
Electric Utilities	--	0.1

* Current secondary standard for SO_2 is 1,300 $\mu g/m^3$, based on a 3-hour averaging time. Standard not to be exceeded more than once per year.

** Discount rate of 10 percent is assumed.

\+ Estimates shown are for effects which were statistically significant at the 10 percent level or less. Estimates would be larger if higher significance levels are used.

-- Equals zero.

present values in 1980, assuming a 10 percent discount rate and an infinite time horizon. The benefits are predicted to be quite small. This is in part because not all of the adverse effects of SO_2 have been measured. It also occurs because so few counties are out of compliance with the standard. In particular, only 18 counties were out of compliance in 1978 for the 3-hour averaging time standard. This compares with over 3,000 counties in the U.S. When the conversion is made to an equivalent standard based on a 24-hour averaging time, only five counties were out of compliance.

Benefits for the Alternative SO_2 Secondary Standard

The current SO_2 secondary standard, based on a 3-hour averaging time, was apparently established to prevent vegetation damage. For materials damage, a longer averaging time is believed to be more appropriate. Estimates were thus developed for an alternative secondary standard (260 $\mu g/m^3$) based on a 24-hour averaging time. The estimated benefits for this standard are shown in Table 1-5. These estimates are also discounted present values. Compared to the previous table, the benefits are considerably larger because many more counties would be out of compliance with this alternative standard.

TABLE 1-5. ESTIMATED BENEFITS IN SECTORS ANALYZED FOR ALTERNATIVE SO_2 SECONDARY STANDARD* (discounted present values for 1980 in millions of 1980 dollars)**

Sector	Basic analysis+	Basic analysis with extrapolations
Household	920	1,101
Agricultural	22	22
Manufacturing	345	1,912
Electric utilities	56	124

* Alternate secondary standard is 260 $\mu g/m^3$, based on a 24-hour averaging time. Standard not to be exceeded more than once per year.

** Discount rate of 10 percent is assumed.

\+ Estimates shown are for effects which were statistically significant at the 10 percent level or less. Estimates would be larger if higher significance levels are used.

Benefits for the Current TSP Secondary Standard

The estimated benefits for the current TSP secondary standard are shown in Table 1-6. As can be seen, the benefits of this standard are considerably larger than for either of the SO_2 standards. In large part, this is due to the fact that more counties are out of compliance with the standard, as well as to the difference in SO_2 and TSP economic effects. As in the previous tables, the entries are discounted present values.

TABLE 1-6. ESTIMATED BENEFITS IN SECTORS ANALYZED FOR CURRENT TSP SECONDARY STANDARD* (discounted present values for 1980 in millions of 1980 dollars)**

Sector	Basic analysis+	Basic analysis with extrapolations
Household	2,299	3,630
Agricultural	--	--
Manufacturing	920	8,029
Electric utilities	--	--

* Current TSP secondary standard is 150 $\mu g/m^3$, based on a 24-hour averaging time. Standard not to be exceeded more than once per year.

** Discount rate of 10 percent is assumed.

+ Estimates shown are for effects which were statistically significant at the 10 percent level or less. Estimates would be larger if higher significance levels are used.

-- Equals zero.

Geographic Distribution of Benefits

As described more fully in later sections of the report, the estimated benefits for the various standards exhibit significant geographic variation. The variation reflects both the distribution of households, industries and farm activity, as well as the geographic variations in air quality. For the current 3-hour SO_2 standard, most of the estimated benefits arise in the East North Central region

(Ohio, Indiana, Illinois, Michigan, Wisconsin).* For the alternative 24-hour SO_2 standard, benefits are heavily concentrated in the East North Central region and the Mid-Atlantic region (New York, New Jersey, Pennsylvania), with additional benefits arising in several other regions. For the current 24-hour TSP standard, benefits are predicted in all nine regions of the country. The largest benefits arise in the East North Central region, the Pacific region (Washington, Oregon, California, Alaska and Hawaii), and the Mid-Atlantic region.

ORGANIZATION OF THE REPORT

The remainder of the report is comprised of 13 sections, bound in six volumes. Section 2 describes the general theory of benefits analysis and presents an overview of the approaches taken in this study. Section 3 describes the air quality and meteorological data. Section 4 describes the structure, estimation, and results of the household sector model. Sections 5 and 6 focus on other approaches to household sector benefits analysis. These include the analysis of residential property values and wage differentials to assess the willingness to pay for air quality. In Section 7, the details of the manufacturing sector model are explained. The electric utilities sector model is the subject of Section 8, while the agricultural sector model is covered in Section 9. The extrapolation procedures

---

* The regional definitions are those used by the U.S. Bureau of Census.

and results for national benefits estimates are described in Section 10. Section 11 presents a comprehensive bibliography of reference material to this study. A summary of the public meeting is included in Section 12, and two additional plausibility checks undertaken following the public meeting are summarized in Sections 13 and 14.

REFERENCES

1. Clean Air Act (42 USC 7401 et seq) as amended by the Clean Air Amendments of 1970 (Public Law 91-604), December 31, 1970; and the Clean Air Act Amendments of 1977 (Public Law 95-95), August 7, 1977.

2. U.S. Code of Federal Regulations, Title 40, Part 50, as revised, July 1, 1979.

SECTION 2

THEORY, METHODS AND ORGANIZATION

SECTION 2

THEORY, METHODS AND ORGANIZATION

INTRODUCTION

The primary objective of this study is to estimate selected non-health benefits of attaining the secondary national ambient air quality standards for SO_2 and TSP. The methods employed in this effort are consistent with the mainstream of current work in benefit-cost analysis. Thus, expositions of both the general theory and the application to environmental problems are widely available.* The purpose of this section is to provide a brief review of the underlying theory and then to show how application of the theory provides the organizing structure for the analysis and for the overall report. More specialized discussions of the theory can be found in the main sections of the report.

Physical Effects of SO_2 and TSP

To set the context for the discussion, it will be useful to consider first the various potential effects of SO_2 and TSP on the

---

* A general reference on benefit-cost analysis is Mishan (1). Baumol and Oates (2), Crocker *et al.* (3), Freeman (4), Mäler (5), and Smith (6) are general references on environmental benefits analysis.

physical environment. Generally speaking, the following categories of effects have been suggested in the literature:

- Soiling
  - Interior and exterior surfaces
  - Fabrics
  - Equipment
- Damage to materials
  - Metals
  - Coatings
  - Building materials
  - Electronic components
  - Fabrics
  - Paper
  - Leather
- Damage to vegetation
  - Crops
  - Forests
  - Ornamental plants
  - Native vegetation
- Damage to animals
  - Livestock
  - Pets
  - Fish and wildlife
  - Other organisms
- Effects on climate
  - Temperature
  - Precipitation
- Reduced aesthetics
  - Visibility

It should be noted that the evidence for these effects is not uniform. For example, the increased corrosion of certain metals exposed to SO_2

is well established.* However, the effects on climate are less well known. Similarly, it should be noted that some effects may be beneficial. For example, certain plant species growing in sulfur-deficient soils have been found to benefit from exposure to ambient SO_2.** However, adverse effects are believed to be the more usual case.

Behavioral Responses to Air Pollution

The economic consequences of the physical effects listed above will depend significantly on how individuals and organizations respond to air pollution. Hence, these responses must be taken into account when estimating the benefits of improved air quality. Possible responses to air pollution may include one or more of the following:

- Ameliorative actions -- These include actions taken in response to pollution damage. In the case of particulate soiling, the response might be increased frequency of cleaning. For metal corrosion, it may be sandblasting and repainting. For plant injury, it could be increased fertilization.
- Preventative actions -- These include actions taken to prevent air pollution damage. In the case of soiling, this may include air conditioning and filtering. Metal corrosion can be prevented or reduced through the use of coatings. Crop damage may be reducible through use of pollution-resistant species.

---

* See Section 7 of this report for references.

** See Section 9 of this report for references.

- Relocation -- Because pollution varies from place to place, one defensive measure is to relocate to a cleaner area. This may include changing residences, job locations, relocating from one building or factory to another, and traveling to more distant recreation sites. In the case of climate or aesthetic effects, this may be the only possible response other than no response at all.

- No action -- One alternative always available is no action. This may be the case if the effects of pollution are not perceived. Or it could be the case if the cost of the other possible actions exceeds the perceived benefits of the action.

The important point is that households, businesses, and agricultural enterprises may take positive steps to prevent or reduce air pollution damage. In cases where such actions are taken, the appropriate measure of economic damage is not the economic damage that would have occurred in the absence of preventative or ameliorative actions; rather it is the cost of these actions plus any residual damage. Presumably this cost will be less than the damage in the no action case, or the action would not have been undertaken. It is therefore important to take these alternative behavioral responses into account -- otherwise, estimates of damages and benefits will be biased. This requires a technical approach which can incorporate optimizing behavior on the part of individuals and organizations. The various models used in this study have this capability.

Economic Benefits of Improved Air Quality

As discussed above, air pollution can produce physical effects which may have economic consequences. As also noted above, the

magnitude of the economic effect will depend on how individuals and organizations respond to air pollution. In addition, however, the measured effect will also depend on the method used in placing a value on the physical damages.

In the case of soiling and materials or vegetation damage, two rather common approaches to valuation have been used. One approach measures the value of the damage by the cost of ameliorative or preventative actions, and in some cases an adjustment is made for residual damage. Another approach assigns a value equal to the intrinsic value of the material lost (e.g., tons of corroded metal times price per ton, or tons of crop lost times price per ton); and in some cases an adjustment is made for the labor cost for installation of the material. With either of the two approaches, the resulting estimate of economic damage is viewed as the economic benefit that would result if air pollution were reduced.*

An alternative method of valuation, and the one generally subscribed to by economists, is based on the concept of willingness-to-pay. The basic idea in this case is that the value of a program to reduce air pollution should be measured by the aggregate amount that members of society would be willing to pay to be in a preferred state

---

* An example study which used the first approach is Fink et al. (7). An example of the latter approach is Salmon (8). In a more recent study, SRI (9) used one or the other approach depending on the availability of data. None of these studies demonstrated that the valuation method used was in fact consistent with how individuals and organizations have actually responded to air pollution effects.

(e.g., clean air) as opposed to a less preferred state (e.g., dirty air). As will be shown in a later subsection, the willingness-to-pay measure of benefits includes two components. The first of these is the conventional notion of a reduction in damages (i.e., savings in cost). The second allows for the possibility that the cost savings may reduce prices and thus stimulate an increase in the quantity of goods and services demanded. Since the increased quantity demanded is directly attributable to improved air quality, the willingness-to-pay measure also includes this as a benefit.

The willingness-to-pay concept is generally the more valid measure of benefits compared to the two other approaches described earlier. This is the case for at least two reasons. First, benefits measured by cost savings, if the latter are measured accurately, will understate true benefits by the value of the increase in demand mentioned above. Similarly, benefits measured by value of lost product may overstate benefits by failing to take into account the price reduction mentioned above. In cases where demand is relatively insensitive to price, the degree of under- or overestimate may be small. If demand is sensitive to price, the inaccuracy can be larger. This will be illustrated further in the next subsection.

The other reason for preferring the willingness-to-pay concept is that, if measured correctly, it will reflect the optimal behavioral responses. In contrast, using, for example, maintenance and repair cost to estimate potential cost savings will be valid only if

maintenance and repair is the optimal behavioral response. If it is not optimal (e.g., if preventative actions would lead to lower cost), then benefits will be overestimated.

Overview of Later Subsections

The remainder of Section 2 is divided into three subsections. The next subsection provides a more specific definition of the willingness-to-pay concept. As will be seen, willingness-to-pay turns out to have a very natural interpretation in terms of the somewhat more widely known concepts of market supply and demand. In particular, the willingness-to-pay for a good or service is identically equal to the integral of the demand function, over the quantity of the good or service demanded. This means that the benefits of improved air quality could be readily estimated if one could determine the demand function for air quality. Unfortunately, there is no established "market" for air quality in which one can observe such a demand function directly. Thus, much of the recent work in air quality benefits analysis has focused on developing other methods of estimating willingness-to-pay.

Among the various methods that have been developed for estimating the willingness-to-pay for air quality, two classes of approaches can be defined. One approach involves looking at behavior in other markets which may be affected by air pollution. Examples include the residential property market, the market for maintenance services, and

the markets for goods and services in which production efficiency (e.g., agricultural crop yields) may be influenced by air pollution. We will refer to these various approaches which rely on behavior observed in related markets as the indirect-market approach. The second broad class of techniques is often referred to as the non-market approach. The majority of these techniques involve survey methods in which individuals are asked about their willingness-to-pay for air quality. Non-market approaches have been increasingly used to evaluate aesthetic benefits of improved air quality.

There is a third broad class of techniques that have been widely used in air quality benefits analysis. These will be referred to as the damage function approach. Previous efforts using this approach have not generally resulted in willingness-to-pay estimates. However, it is possible to extend these techniques in that direction (see Section 9 of this report). Damage function approaches typically couple mathematical dose-response relationships* with estimates of receptor** inventories and, for example, unit maintenance and repair costs to estimate economic damages.

Most of the analyses in this study are examples of the use of market data and indirect-market approaches to estimate benefits. None of the non-market approaches were attempted because of the time and

---

* A mathematical function relating physical damage to air pollution exposure.

** Items which "receive" (are affected by) air pollution.

resources that would be required to undertake a survey. The damage function approach was used in the agricultural sector analysis (see Section 9) and coupled with a market model to evaluate benefits. Damage functions were not used more widely, however, for several reasons. These included:

- The problems discussed earlier in valuing the identified physical damages.
- The absence of data on the distribution of receptor inventories.
- The unavailability of damage functions for many types of materials.
- The absence of damage functions for more subtle types of effects such as efficiency losses in machinery and equipment containing materials affected by air pollution.

The second subsection following is thus concerned with indirect-market approaches for estimating air quality benefits.

Given the indirect-market approaches used in this study, a natural organizing framework for the study was along the lines of economic sectors; that is, the various groups that participate in the markets potentially affected by air pollution. Division of society into various sectors is analytically very useful. This is because it allows separate characterization of the optimizing behavior, and thus the response to pollution, in each sector.

The final subsection discusses the economic sectors so defined and identifies the particular sectors analyzed in detail. On the final demand side of the market, the household sector is analyzed in detail. On the supply side of the market, subsets of the manufacturing, electric utility and agricultural industries are analyzed in detail. Potentially important sectors not considered in this study are the commercial and government sectors. One reason for omitting the latter sector was that the appropriate form of optimizing behavior was not clear.

THE DEFINITION OF ECONOMIC BENEFITS

In broad terms, the economic process involves the conversion of society's stock of resources into goods and services, and the sale or exchange of these goods and services in the marketplace. This activity generates economic benefits by allowing people to consume and produce desired combinations of goods and services. For example, manufacturing firms consume capital, labor and raw materials in order to produce saleable goods and services. Households can also be viewed as producing services by consuming various inputs. One example would be the consumption of gasoline, tires and automobiles to produce transportation services. Or perhaps more to the point, they also consume cleaning supplies and services in order to "produce" attractive housing services.

Changes in ambient air quality can alter these market relationships, including the efficiency of production activities, in a variety of ways. These alterations can thus increase or decrease the benefits enjoyed by society. However, before we address the linkage between air quality and economic benefits, it will be useful first to consider the concept of economic benefits in a broader sense.

Willingness to Pay

In the most general case, one can say that economic benefits are generated whenever a transaction, such as the sale of a good or service, takes place. Economists generally agree that any attempt to measure these benefits should be based on individuals' own valuations of the benefits, as evidenced by their "willingness to pay" for the opportunity to engage in the transaction. Evidence of willingness-to-pay can thus often be observed by analyzing market transactions.

To consider a more specific case, suppose that we observe sales of a particular good taking place at a price of $1 per unit. We can infer that each purchaser of this good is willing to pay at least $1 to have it rather than go without it. Total expenditures for this good thus represent a lower bound on the sum of all purchasers' willingness to pay for the good. In fact, of course, they may be willing to pay much more.

To be able to infer actual willingness-to-pay from observed behavior clearly requires more information. Exactly the needed

information is provided by the fact that the marginal buyer (i.e., the buyer who would not buy if the price were any higher) is willing to pay exactly the price he pays and not one penny more. By using this fact, we can find a differential equation representing market behavior which, in principle, can be used to measure willingness-to-pay exactly.

Let q denote the total quantity of the good purchased per unit of time, and let p(q) represent the market price corresponding to q. In this case, the marginal willingness-to-pay when (say) Q_0 units are purchased is simply the prevailing market price:

$$\frac{dW}{dq} = p(Q_0) \tag{2.1}$$

where W is willingness to pay. Total willingness-to-pay can then be found by solving this differential equation for W which yields

$$W = \int_0^{Q_0} p(q)dq \tag{2.2}$$

Equation (2.2) provides the fundamental relationship that economists use to translate the willingness-to-pay principle of benefits measurement into practice. What Equation (2.2) says is that if we can find the market relationship between price, "p", and quantity purchased per unit of time, "q", [this is the relationship we

have denoted by p(q)], we will have exactly the relationship that is needed to measure willingness-to-pay.

This relationship between p and q is nothing other than what economists call the "market demand function" which relates price and quantity demanded for goods and services. Of course, variables other than price and quantity are important in this relationship. For example, we know that income, population size, income distribution, and many other factors influence demand.* For ease of exposition and notation here, however, we shall retain our convention of expressing explicitly only price and quantity.

This procedure for estimating individuals' willingness-to-pay can be illustrated using simple diagrams from elementary economics. In Figure 2-1, we have drawn a demand curve (a "demand curve" is a demand function with all variables other than price and quantity held constant). At quantity Q_0, total willingness-to-pay is given by the area under the demand curve up to Q_0, which is the shaded area in Figure 2-1.

---

* Note that the calculation of total willingness-to-pay in Equation (2.2) involves aggregating individuals' willingness-to-pay. Thus, population size and income are important influences not only on demand, but also on total willingness-to-pay.

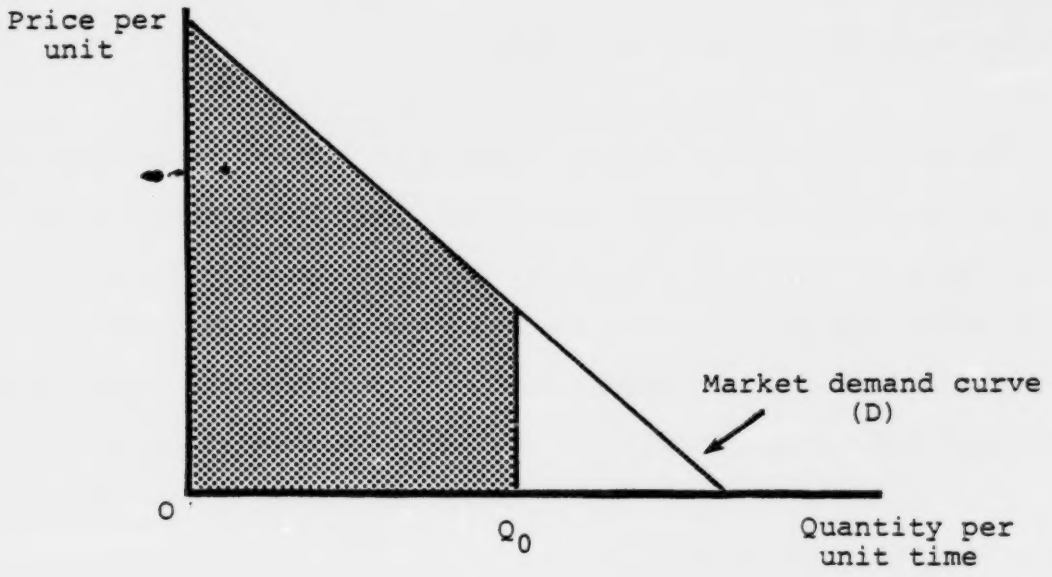


Figure 2-1. An illustration of the calculation of total willingness-to-pay.

Consumers' Surplus

Frequently in cost-benefit analysis, willingness-to-pay is measured net of any charges levied upon customers for the good or service in question. When this is done, the result is called "net willingness-to-pay", or more frequently, consumers' surplus. The "consumers' surplus" measure represents what customers would be willing to pay over and above what they do pay. This concept is illustrated in Figure 2-2, where it is assumed that a price of P_0 is charged for each of the Q_0 units purchased. The shaded area in this figure represents consumers' surplus (or net willingness-to-pay). The total user expenditures that have been netted out of willingness-to-

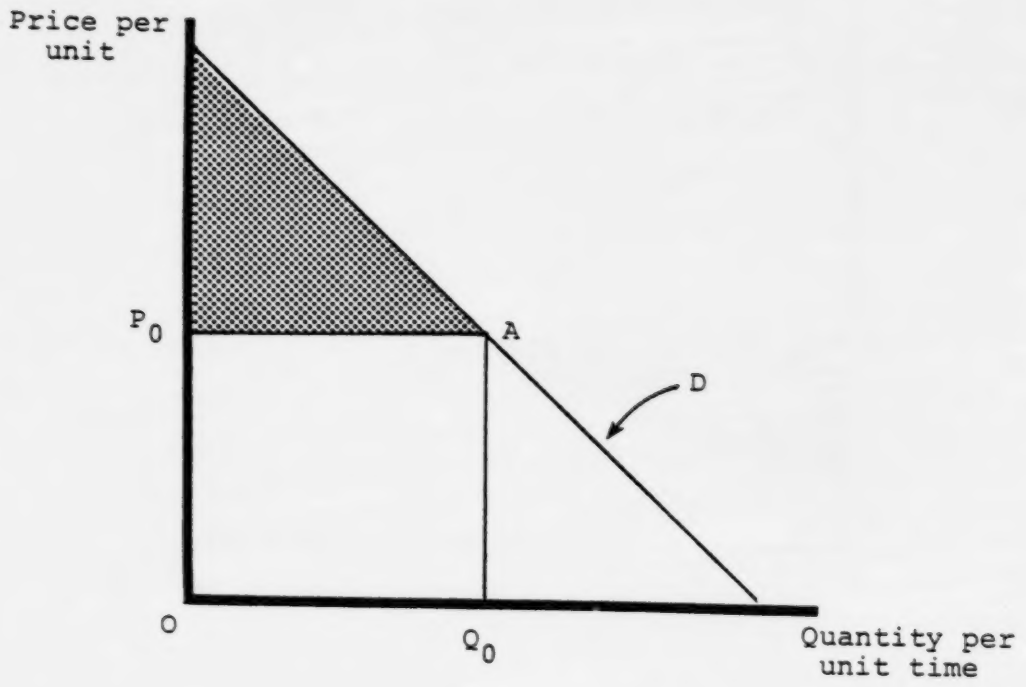


Figure 2-2. Illustration of the calculation of consumers' surplus.

pay are given by the rectangle OP_0AQ_0. (Compare Figure 2-2 with Figure 2-1.)

Producers' Surplus

Corresponding to consumers' surplus is the concept of producers' surplus which can be simply illustrated by a figure such as Figure 2-3. In that figure, D is the demand curve. However, in Figure 2-3, we have added the marginal cost curve, MC, which represents the cost of producing one additional unit. As drawn, some firms are able to produce at lower cost than others. Thus, with price

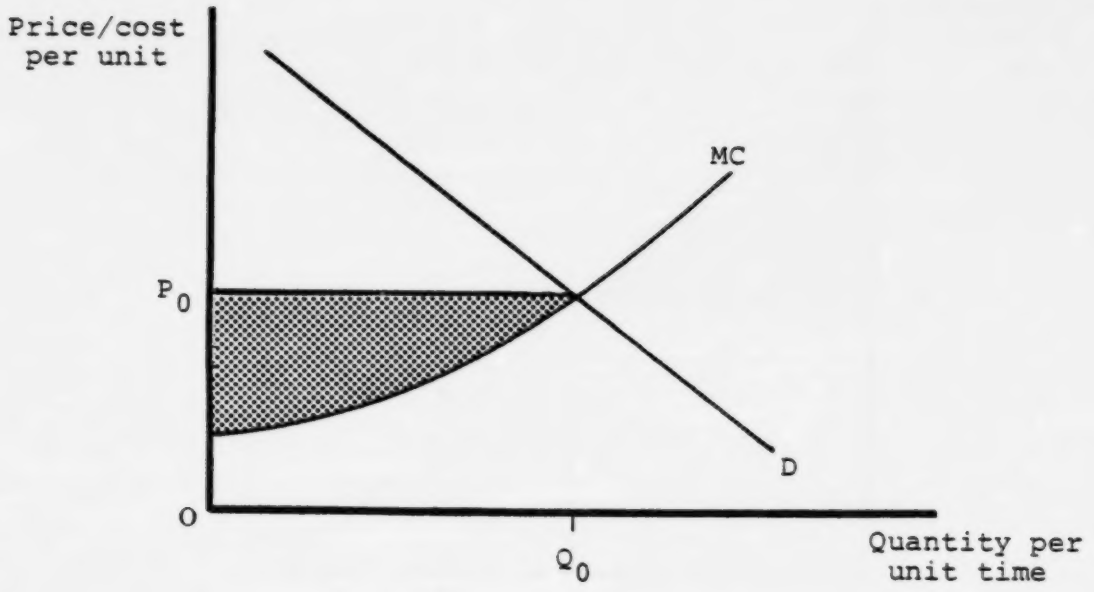


Figure 2-3. Producers' surplus.

set at P_0 -- where the demand curve intersects the marginal cost curve — these firms earn a surplus represented by the difference between price and marginal cost, or the shaded area in Figure 2-3. Since this surplus ultimately flows back to members of society (as income to fixed factors), the producers' surplus is considered to be as much a benefit as the consumers' surplus.

The sum of consumers' and producers' surplus if often referred to as economic surplus. Economic surplus can be illustrated as the shaded triangle in Figure 2-4.

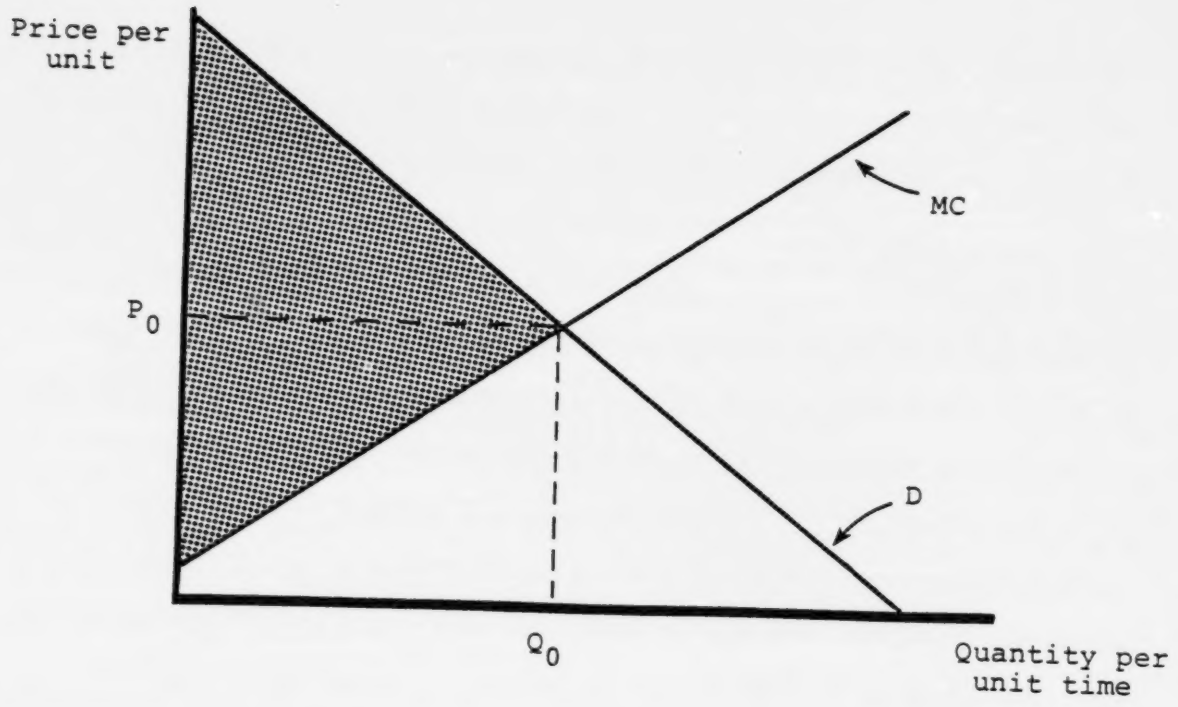


Figure 2-4. Consumers' and producers' surplus.

Benefits of a Particular Action or Event

The economic surplus illustrated previously in Figure 2-4 represents the economic benefit to society that results from transactions for a particular good or service. Note also that any action or event which leads to a change in market supply or demand will also change the magnitude of the economic surplus. In particular, as can be seen in Figure 2-4, the economic surplus will be increased by any action or event which causes an upward shift in the market demand curve or a downward shift in the market supply curve. The economic surplus will be decreased by any action or event which causes the opposite shift in either curve. Since an increase

(decrease) in economic surplus represents an increase (decrease) in economic benefits to society, this observation provides the basis for evaluating the benefits (costs) of a particular action or event.

To be more specific, suppose the particular event is an innovation in manufacturing which lowers the cost of producing some consumer product. Thus, the effect of the innovation is to produce a downward shift in the marginal cost (supply) curve for the product from MC to MC'; i.e., the cost of producing each additional unit is less. This effect is shown in Figure 2-5 which represents the market for the consumer product. As can be seen, the downward shift increases the economic surplus in the market by an amount given by the shaded area. The magnitude of this increase represents the economic benefits of the innovation per unit of time (e.g., per year). Of direct benefit to consumers of the product is the fact that the price of the product declines from P_0 to P_0'.

Measuring Benefits by Cost Savings

The change in economic surplus shown previously in Figure 2-5 represents the benefits of the innovation that led to a lowering of production costs from MC to MC'. Referring back to Figure 2-5, note that the change in surplus consists of two components. Area OAC represents the savings in the cost of producing the original level of output Q_0. Area ABC represents the additional surplus generated when

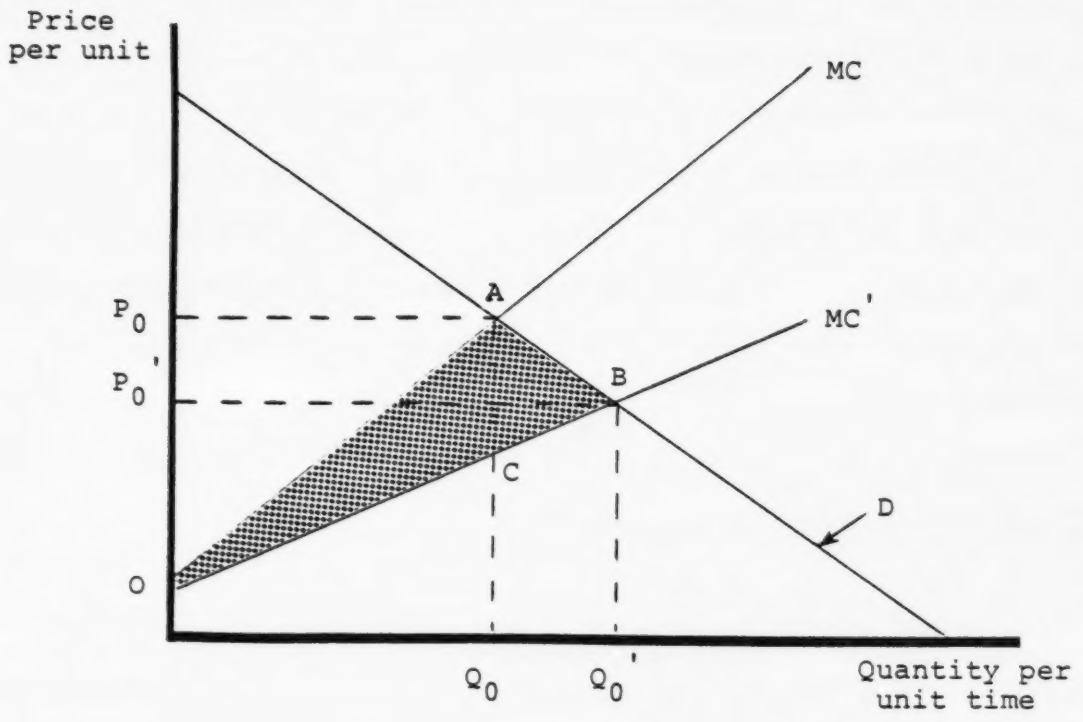


Figure 2-5. Change in economic surplus.

the decline in price from P_0 to P_0' led to an expansion of sales from Q_0 to Q_0'.

The discussion above thus indicates that the use of cost savings to evaluate the economic benefits of an action or event is consistent with the concept of economic surplus. Benefits measured by cost savings will always provide a lower bound estimate of the benefits measured by the change in economic surplus. The difference between the two measures is given by the area ABC.

For given supply conditions, the size of the area ABC will depend on the slope of the demand curve (sensitivity of demand to price). When demand is insensitive to price, the demand curve will be steeply sloped, area ABC will be small, and cost savings will closely approximate the change in surplus. When demand is sensitive to price, the demand curve will be flatter, area ABC will be larger, and the use of cost savings to approximate the change in surplus will be less accurate.

Alternative Measures of Economic Benefits*

The definition of economic benefits developed in the previous sections is based on the concepts of consumers' and producers' surplus. These concepts are widely used in empirical benefit-cost analysis because they can be readily calculated from knowledge of "ordinary" demand and supply curves. From a more theoretical viewpoint, the concept of consumers' surplus (C'S) has a certain imprecision, which has led to the development of four alternative definitions of benefits. These include the concepts of compensating variation (CV) and equivalent variation (EV), which are appropriate for measuring the benefits of a price change; and compensating surplus (CS) and equivalent surplus (ES), which are appropriate for quantity

---

* This section discusses certain theoretical refinements which the general reader may wish to skip over.

change. These four measures are generally viewed as theoretically more correct than ordinary consumers' surplus (C'S).*

In a recent paper, Willig (10) has provided an analytical basis for comparing the C'S, CV, and EV measures of economic benefits. The general conclusion is that for price decreases, the measures are related as follows:

$$CV \leq C'S \leq EV \ .$$

Furthermore, the differences between the three measures are small if: (1) the magnitude of the measured surplus is small relative to the consumer's income; or (2) the income elasticity of demand for the good or service under consideration is small. Since air quality benefits are believed to be small relative to income, the Willig results support the use of the ordinary consumers' surplus measure as an approximation to the CV and EV measures. In one part of this study (see Section 4), it is actually possible to use the more exact CV measure.

More recently, Randall and Stoll (11) have established corresponding results for the C'S, CS, and ES measures. Since a reduction in air pollution is a quantity change, it might seem that their results are more appropriate here. However, as will be shown

---

* Precise definitions of the CV and EV measures can be found in any of the references cited at the beginning of Section 2.

later in this section, it is possible to transform the problem of analyzing quantity changes in air pollution to one of analyzing price changes. Thus, it is the Willig results that are of interest here.

Measuring Benefits in Intermediate Markets*

In the discussion to this point, it has been assumed that the demand side of the market is represented by consumers, and thus that the goods and services involved are final goods. It is possible, of course, for actions or events to affect directly the prices of intermediate goods (i.e., goods used in the production of other goods) and through them the prices of final goods. The demand for the intermediate goods is a derived demand, based solely on their value in producing other final goods for consumption. Conceptually, consumers' surplus can only accrue to consumers of these final goods. As a result, measuring the benefits of an action or event which lowers the cost of an intermediate good can be more complex than is indicated by the example presented earlier. For example, in cases where many final good markets are affected, the measurement of these benefits would seem to be an extremely involved task requiring the calculation of benefits accruing in all of these final good markets.

Fortunately, however, the benefits that accrue in the form of consumers' surplus in the various final good markets can be

---

* This section discusses certain theoretical refinements which the general reader may wish to skip over.

approximated using data on demand and cost relationships in the intermediate market alone. This is the case because of the relationship between derived demand for an intermediate product and demand in the final good market. The critical issue then is how accurately the benefits measured in the intermediate market approximate the benefits in the final good markets.

A partial answer to the above question was developed by Schmalensee (12). He showed that two conditions were sufficient to guarantee that the approximation would be exact if there were one final good: competitive markets and infinitely elastic input supplies. This result has been independently generalized to the case of an intermediate good used in the production of more than one final good (13). In the case where markets are monopolistic, Schmalensee also showed that benefits measured in the input market would underestimate actual benefits, and thus represent a conservative estimate.

A more recent generalization of the Schmalensee results was provided by Just and Hueth (14). Their generalization was in two directions: (1) a partial relaxation of the assumption of infinitely elastic input supplies, and (2) an extension to the case of a sequence of intermediate markets. Their conclusion was that the overall impact of an event in some intermediate market can be measured by the change in economic surplus in that market alone if the general equilibrium supply and demand curves for the market are used. If ordinary supply

and demand curves are used, then benefits in that market alone will be measured and total benefits will be underestimated; i.e., estimates will be conservative.

Summary

This subsection has shown how the concept of willingness-to-pay can be used to derive a measure of economic benefits, and thus provide a basis for evaluating the benefits of a particular action or event. The following subsection describes how these concepts can be applied to the problem of measuring the benefits of improved air quality.

INDIRECT-MARKET APPROACHES FOR ESTIMATING AIR QUALITY BENEFITS

As indicated in the preceding subsection, one can evaluate the benefits of a particular action or event by calculating the change in economic surplus caused by the action or event. Thus, for example, if one could observe the demand curve for air quality, it would be possible to calculate the willingness-to-pay for an improvement in air quality. Unfortunately, however, no market for air quality exists and thus the demand curve for air quality cannot be observed directly. .

An alternative approach is to observe how air quality influences the behavior of the members of society in other markets. Although members of society may not directly interact in a market for air quality, they do interact in markets for many other commodities and

services potentially affected by air quality. As one example, we know from field studies that sulfur oxides cause corrosion damage to steel structures used by industrial firms. By observing the extent to which increased air pollution causes firms to undertake more frequent maintenance, or to undertake other preventive measures, one can infer the extent to which an improvement in air quality would reduce the costs incurred by these firms. The savings in cost, or more specifically, the downward shift in the marginal cost curve for these firms, could then be used to calculate the benefits of improved air quality.

The purpose of this subsection is to show how the effects of air quality on the supply or demand for other marketed goods and services can be used to measure the benefits of improved air quality. Of particular interest in this section will be two issues:

- How can data observed in related markets be used to estimate air quality benefits?
- Are there benefits which cannot be observed in market behavior?

The key to answering the first question has already been suggested. Air pollution may influence costs of production for firms and the demand for products and services by individuals. We also know from the previous section that any action or event which alters supply or demand relationships can alter the economic surplus in individual

markets and thus generate benefits or costs. This leads us to consider two broad categories of effects:

- The effect of air pollution on the costs of production by firms.
- The effect of air pollution on the demand for goods and services by households.

The key to answering the second question requires determining whether there are air pollution effects which do not result in changes in market supply and demand conditions. It turns out that such effects do exist. These are also addressed in this section.

Air Pollution Effects on Firms*

Businesses, industrial firms, and agricultural enterprises combine labor, capital and materials inputs to produce goods and services. If these firms are adversely affected by air pollution, then their costs of production may also be affected. Several examples of this have already been mentioned: increased maintenance and repair activity as a result of corrosion damage, increased cleaning activity in response to soiling, reduced crop yields because of vegetation damage, etc. Each of these effects, if present, would result in higher costs of production, for a given level of output, compared to a situation with less air pollution.

---

* More detailed discussions of these effects can be found in Sections 7, 8, and 9.

Recall from the previous section that one way of representing production relationships is by means of the marginal cost or supply curve for an industry. The marginal cost curve depicts the cost of producing each additional unit of output. If the industry is characterized by constant unit costs at every level of output, the marginal cost curve will be horizontal. Or, as indicated previously in Figures 2-3 to 2-5, marginal cost may increase at higher levels of output.

If firms in the industry are affected by air pollution, then, in these cases, one can view the marginal cost curve for the industry as functionally dependent on the level of air pollution. This is shown in Figure 2-6 where the marginal cost curve MC is taken to be a function of both the level of output Q and the level of air pollution S. Also shown in the figure is the marginal cost curve when air pollution has declined from S to S'. As indicated in the preceding section, the benefits of the improvement from S to S' are given by the change in economic surplus which is shown in the figure as the shaded area. Note that although the pollution effect is on the supply side of the market, consumers share in the benefits as a result of the price decrease from P_0 to P_0'.

It is very possible, of course, that air pollution may affect production costs in more than one industry. In this case, an improvement in air quality would shift the marginal cost curve in each of these industries. Hence, calculating the benefits of a change in

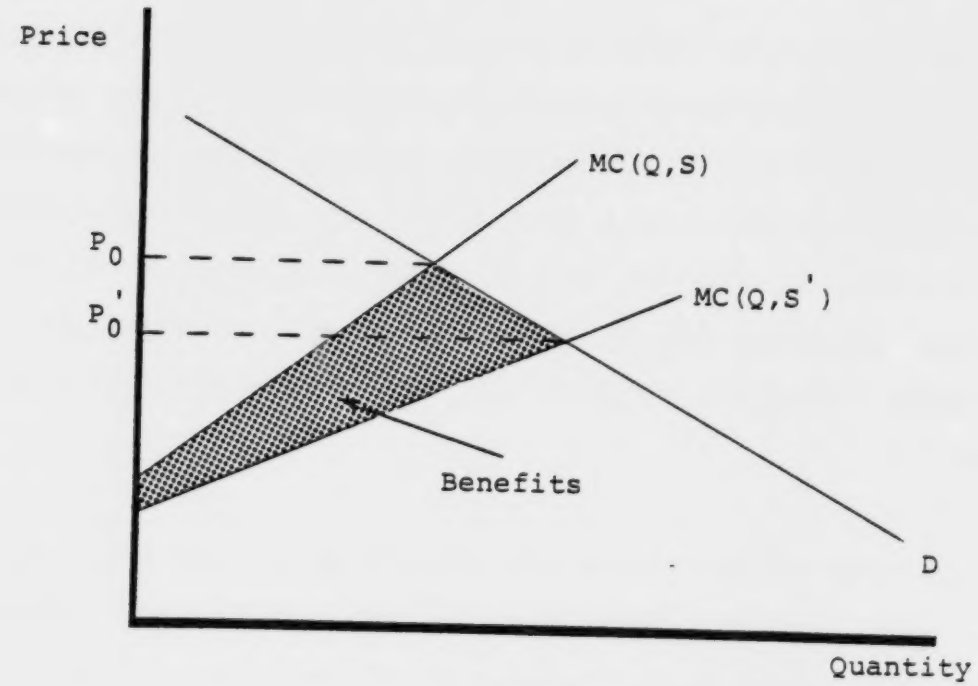


Figure 2-6. Change in consumers' and producers' surplus due to an improvement in air quality from S to S'.

air quality requires calculating the change in economic surplus in each directly affected industry. The basic method in each case, however, is the same.

Air Pollution Effects on Households

The pollution effects described in the previous paragraphs were assumed to be incident directly on the supply side of the market -- businesses, industries, agricultural enterprises, etc. It is also possible, of course, for pollution to affect the demand side of the market, and in particular, to affect households (consumers) directly.

Effects in this case may include those already mentioned such as soiling and materials damage, reduced aesthetic values, etc.

Demand Shifts--

Consider, for example, the possibility that demand for use of a recreation area may depend on the environmental attractiveness of the area. In this case, if the environmental attractiveness improves, e.g., through improved air quality, then one would expect the demand for use of the area to increase.

In terms of the earlier diagrams, the relationship between air quality and demand for recreation can be depicted as in Figure 2-7. Note that in the figure, the demand for the recreation activity is represented by a demand curve which depends parametrically on air quality S, just as production costs did in the previous section. This implies that with an improvement in air quality from S to S', the demand curve shifts upward, indicating that consumers demand more recreation services at every price. For this type of an effect, it can be shown (15) that under certain reasonable circumstances, the shaded area between the two demand curves in the figure is the benefit of the improved air quality. Note that the shaded area is simply the change in economic surplus as defined previously.

Implicit Price Shifts--

In some respects, the effect of air quality on recreation demand is atypical of the effect on the demand for other household goods and

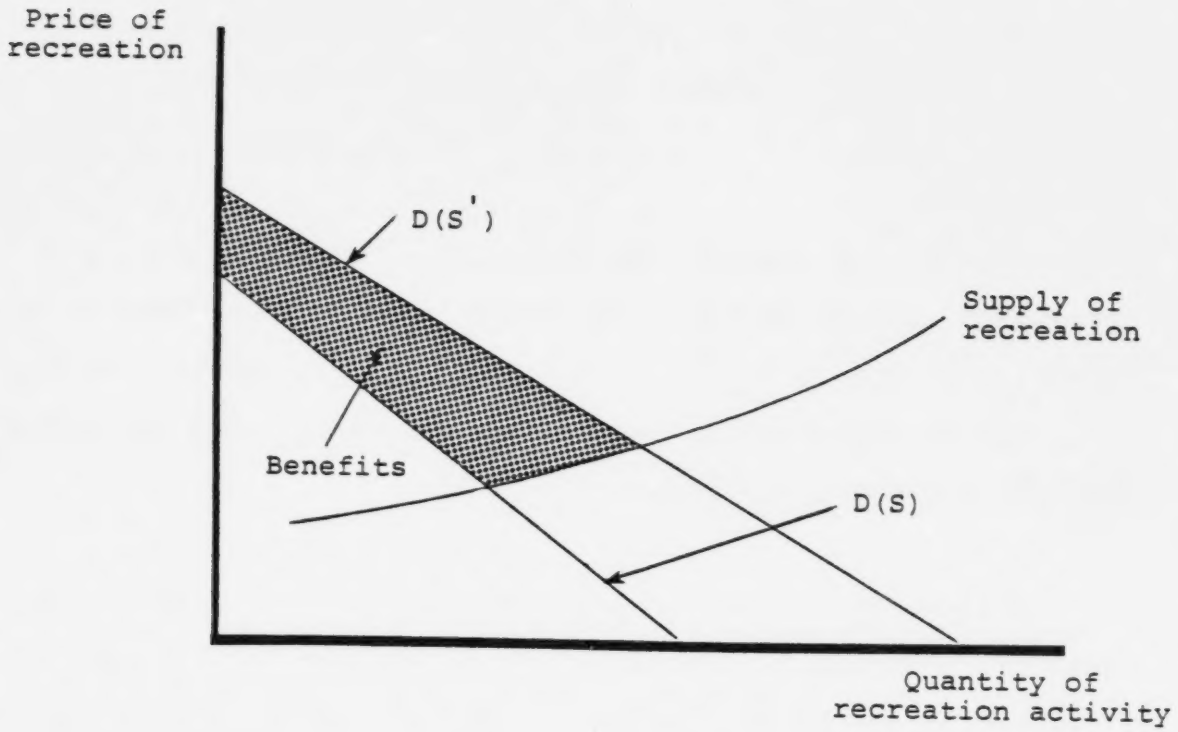


Figure 2-7. Change in consumers' and producers' surplus due to an improvement in air quality from S to S'.

services. For example, one might expect soiling and materials damages due to air pollution to influence household demand for goods and services such as soaps and detergents, laundry and dry cleaning services, interior and exterior paints, and so on. In these cases, however, an improvement in air quality may lead to reduced demand for these items, rather than increased demand as was the case with recreation.

The difference arises because of the differing interpretation as to the exact way in which various goods and services, and therefore

"air quality", enter consumers' utility functions.* Since recreation is a final good, one would expect it to enter directly in the utility functions. Similarly, one might also assume that soaps and detergents are final goods and thus appear in the utility functions. If we do this, however, we must then allow that air quality can also enter the utility function, since we suspect that dirtier air may increase demand for cleaning items, or at a minimum, affect the satisfaction associated with the existing level of consumption of these items.

In another interpretation, however, soaps and detergents and the like are "final goods" only in the way the term is used by economists in constructing the national income accounts. Another way to look at the problem is that cleaning items are really derived demands based on a more fundamental consumer demand for "cleanliness". That is, consumers derive utility from cleanliness, not from detergent. Detergent, and clean air, contribute to satisfying the final demand for cleanliness.

The implication of the second interpretation is twofold. First, in this interpretation, goods and services like cleanliness enter the utility function rather than individual goods and services like detergent. To make this distinction clear, we will use the phrase "final goods and services" to refer to things like cleanliness, and the phrase "intermediate goods and services" to refer to things like

---

* A utility function is a relationship expressing a consumer's preference for different combinations of goods and services.

soap and detergent (and air quality). A second implication of this approach is that we therefore impose certain restrictions on the form of the consumer's utility function. In particular, it means that we have assumed that air quality enters the utility function only indirectly as opposed to appearing directly. We discuss the implications of this further below.

To illustrate the situation more clearly, suppose we define a final good called "household operations", which is presumed to enter directly into consumers' utility functions. Household operations might include all laundry and cleaning activities, and other forms of household maintenance. We also assume that some natural index or measure of the quantity of household operations can be defined.* Under this assumption, it is then possible to think in terms of a demand function for household operations, which relates the quantity of household operations demanded by consumers to the price of household operations. A graph of such a function is shown in Figure 2-8.

In this formulation, the remaining question is how to define the unit cost (or price) of "supplying" household operations. As a start, we know that this cost will depend on the prices of the intermediate goods used in household operations, namely, the prices for detergent, dry cleaning, etc. In addition, if air pollution increases the amount

---

* For a detailed discussion of how such indices can be formed, see Section 4 of this report.

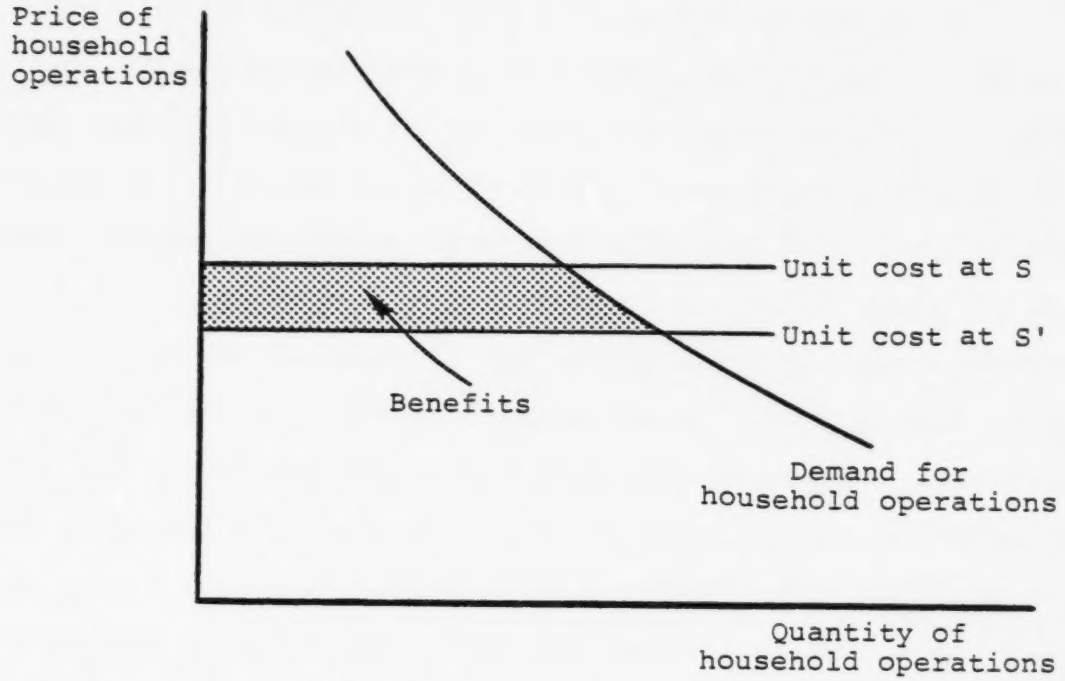


Figure 2-8. Benefits of an improvement in ambient air quality.

of detergent, etc., required to maintain a given level of household operations (e.g., a given level of cleanliness), then the price will also depend on the level of air quality. Thus, for a given set of fixed prices for detergent, etc., the unit cost or price of supplying household operations will depend parametrically on air quality S. This relationship is shown in Figure 2-8 for two different levels of air quality, S and S'. Note that when air quality improves from S to S', the unit cost curve for household operations shifts downward. The shaded area in the figure is a measure of the economic benefits generated.

A comparison of Figures 2-7 and 2-8 highlights the differences in the two approaches. In Figure 2-7, recreation and air quality both enter the utility function. Hence, as air quality improves, demand for recreation shifts upward and benefits are generated. In Figure 2-8, the final good "household operations" enters the utility function and the demand for household operations is independent of air quality. However, in the latter case, the cost of household operations depends on air quality. Thus, as air quality improves, the cost of household operations shifts downward and benefits are generated. The latter situation is thus analogous to the earlier discussion for firms. That is, one might view households as "producing" household operations by using inputs such as detergent and labor. Air pollution increases the cost of this production by increasing the quantity of inputs required to produce a given level of household operation.

In general, the consumers' utility functions will contain as arguments a variety of final goods and services in addition to recreation and household operations. The use of some of these other goods and services may also be influenced by air quality. In these cases, improvements in air quality will lead to shifts in demand or shifts in the prices for the final goods. Benefits can thus be calculated by using one or the other of the techniques described above.

In a more advanced analysis, one will also want to take into account the interrelationship among the expenditures for different categories of goods and services. This interrelationship is imposed

by the constraint that total expenditures be less than or equal to total income. The household sector analysis in Section 4 incorporates this feature.

Other Indirect-Market Approaches

The two previous sections described the indirect-market approaches applicable to firms and households. While the techniques described have broad applicability to markets in general, considerable attention in the literature has also been given to examination of two more specialized markets -- the residential property market and the labor market. For completeness, these are reviewed briefly below. More detailed discussions can be found in Sections 5 and 6 of the report.

The Residential Property Market--

Many previous studies have developed estimates of air quality improvement benefits to households by analyzing differences in residential property values.* The underlying hypothesis in these studies is that residential property values will reflect not only housing quality, but also site-specific attributes such as location, neighborhood characteristics, availability of services, and environmental quality including air quality. Various studies have thus attempted to estimate the willingness to pay for air quality by

---

* See Section 5 for specific references.

examining differences in property values (or rents) while statistically controlling for the other determinants of property value. Estimates of willingness to pay can then be used to estimate the benefits of an improvement in air quality.

An analysis of residential property values is not easily adaptable to the problem of estimating the non-health benefits of the secondary standards. This is because property values are likely to reflect all perceived effects of air pollution -- both health and non-health effects. Hence, benefits estimates based on property value differentials are likely to be larger than estimates based on analysis of expenditures for household operations and other items, using the techniques described earlier.

The fact that property value-based benefits estimates include a broader range of effects is still useful information, however. In particular, by comparing estimates using this approach with estimates based on the approach described earlier, the plausibility of the latter can be assessed. This is the use made of property value techniques in this study (see Section 5).

The Labor Services Market--

A number of studies have also developed air quality benefits estimates by analyzing geographic differences in labor wage rates.*

---

* See Section 6 for specific references.

The underlying hypothesis in this case is that wage rate variations will reflect differences in individual attributes (e.g., educational attainment), differences in job characteristics (e.g., health and safety hazards), and locational amenities such as climate, access to services, and environmental quality. Various studies have thus attempted to estimate air quality benefits by examining wage rate variations across geographic areas while controlling statistically for the other wage rate determinants.

As in the case of the property value technique, air quality benefits based on wage rate variations are likely to reflect both health and non-health benefits. Estimates based on this technique are thus used in this study in the same way as the property value estimates. That is, they are used to provide an upper-bound estimate of benefits as a cross-check on estimates derived by examining air quality effects on the prices for final goods and services.

Air Quality Benefits Not Observable in Market Behavior

Recall that in the absence of a market for air quality, the technical approach used in this study relies on analyses of other affected markets. As one might expect, some of the benefits of air quality improvement cannot be identified in this way. For example, some members of society may attach a value to environmental quality, per se, independent of any directly received benefit or enjoyment. This may arise, for instance, as a desire to preserve the environment

for later generations, or for later enjoyment by existing generations. These benefits are thus sometimes referred to as "bequest values" or "option values", respectively. These benefits cannot be observed by looking at behavior in other markets.

Some of the aesthetic values associated with a clean environment may also be difficult to detect in other markets. One example of this is the value of improved visibility. This value is difficult to observe in other markets because improved visibility has less of a direct association with the consumption expenditures of households or production decisions by firms. The residential property value and labor market techniques may capture some visibility benefits. The recreation example described previously may also be useful. However, the other indirect-market approach based on household consumption expenditures is not likely to capture visibility benefits.

Pollution effects not offset by preventative or ameliorative actions (e.g., increased cleaning frequency) may also not be captured by analysis of household expenditures. For example, suppose pollution causes increased soiling but no action is taken in response. In this case, a loss of utility may occur, but it would not be observable in market behavior since no behavioral change has occurred.

In contrast, pollution effects on firms may be observable even if no behavioral adjustment takes place. For example, if air pollution reduces crop yields, the loss of output can be observed even if no

attempts are made to increase yield by, say, increased fertilization. Or, if air pollution causes an unperceived loss of efficiency in equipment or machinery, the loss of productivity can be observed in the firms' economic performance even if no ameliorative action is taken. Thus, the possibility of underestimating air quality benefits using indirect-market approaches is more likely to be a problem in the case of households than in the case of firms.

Lastly, it seems likely that certain effects of air pollution on the ecosystem, or on climate, would be difficult to observe in market behavior. For example, if air pollution led to the extinction of certain plant or animal species, the loss would be measurable only to the extent that it eventually had a later effect on, say, the food chain, and thus ultimately on agricultural markets. In other circumstances, the effects may not be observable in market data.

Aggregation and Coverage of Benefits Categories

The previous sections described a number of techniques for estimating air quality benefits by observing market behavior. In the case of air pollution effects on businesses, industries, and agricultural enterprises, the idea was to look for changes in production and cost relationships. In the case of households, it was suggested that air pollution effects may change demand relationships, or the implicit price of composite household activities, depending on how one views air pollution as affecting consumers' utility.

The methods described for both firms and households are basically partial equilibrium techniques. That is, the analysis for firms is focused on production relationships, while assuming that demand schedules are fixed;* the analysis for households focuses on consumption activities while assuming that market prices are fixed. Under these assumptions, total benefits are approximately given by the sum of the benefits calculated in the two sets of analyses. All previous analyses of air quality benefits appear to have been based on partial equilibrium approaches. Ideally, one would like to consider the problem using a general equilibrium approach which would take into account the interrelationship of the effects in the different sectors. However, such an approach has not been feasible in empirical applications to date.

In the case of the household sector, it was noted that two additional indirect-market approaches also exist, based on the residential property and labor services markets. It was also noted, however, that benefits estimated with these techniques include some overlap with each other and with estimates based on household consumption decisions. Hence, it is not appropriate to add these benefits estimates together in developing a total for the household sector.

---

* That is, there may be movements along the demand curve, but the curve itself remains fixed.

Lastly, it was suggested that indirect-market approaches may not be able to identify certain types of air quality benefits. These are believed to include benefits generally referred to as "option" values and "bequest" values; certain aesthetic benefits; and climate or ecosystem effects which do not ultimately impact economic markets.

ORGANIZATION OF THE STUDY AND REPORT

The previous sections have reviewed the general theory underlying benefits analysis in general and the indirect-market approach in particular. In applying these broad concepts to a practical problem, many specific decisions are required concerning scope, methods and validation. The purpose of this section is to summarize the decisions that were made, and in so doing, to provide an overview of the remainder of the report.

Organizing Framework

The overall logic of the study can be summarized as shown in Figure 2-9. At the top of the figure, the overall scope of the study, the non-health effects of TSP/SO_2, is identified. At the second level in the figure, the alternative methods for estimating non-health benefits are listed. As indicated previously, the basic approach in this study can generally be viewed as a combination of indirect market

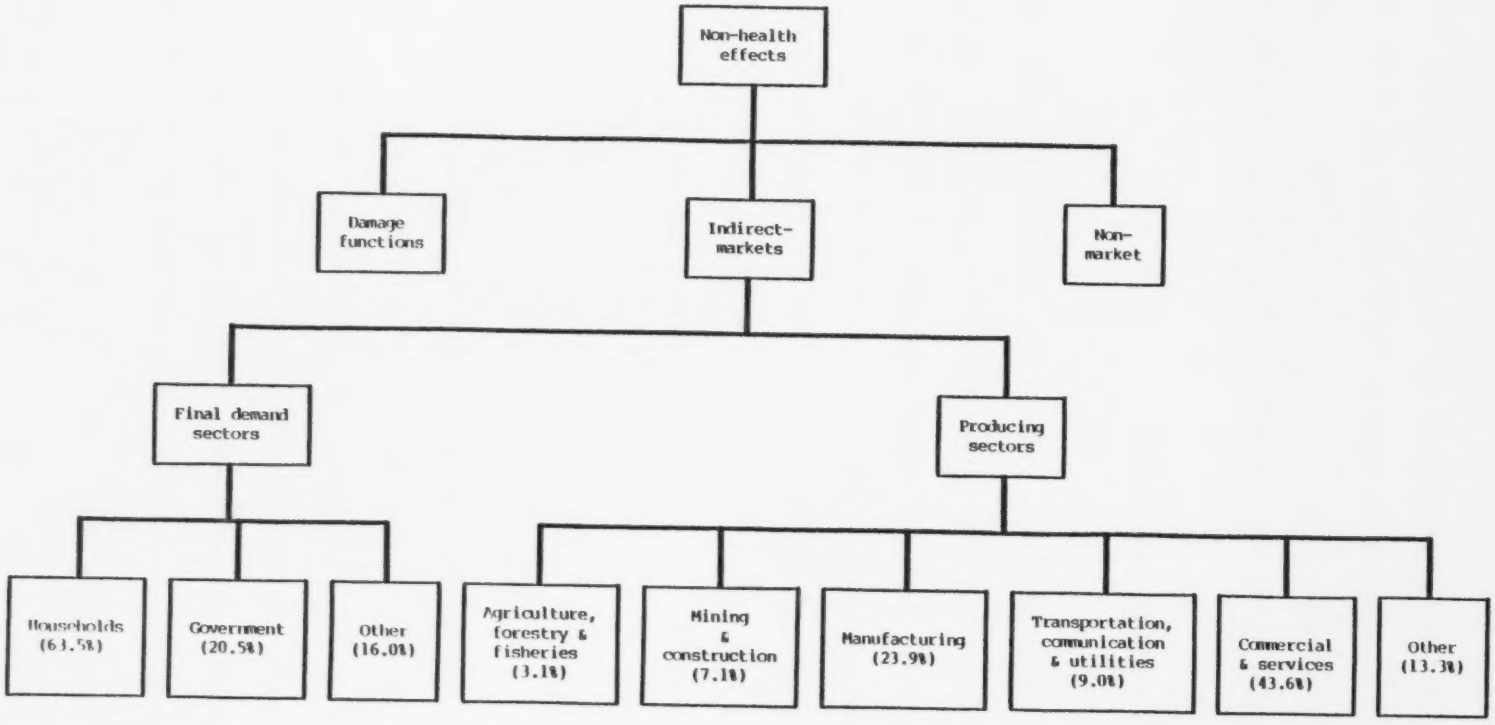


Figure 2-9. Organizing framework for the study.

approaches.* Given this approach, the next step is to identify the various markets, or economic sectors, that might be affected. Recall that within a partial equilibrium framework, we consider final demand effects and supply side effects separately. The third level in the figure indicates the separation, and the fourth level lists the various economic sectors associated with each side. The percent figures included in the boxes indicate the percent of final demand accounted for by each demand sector and the percent of gross national product (GNP) accounted for by each producing sector (16).

Selection of Sectors

Given the sectors identified in the figure, the next step in the study involved assessing the availability of data and models for analyzing effects in each sector. As will be discussed, we did not conduct analyses for all of the sectors. Some sectors were excluded because available data were limited (e.g., air quality data in timber-growing regions). Others were excluded because the nature of the industry made it difficult to define the location of the industry with respect to air quality (e.g., the transportation industries). The specific conclusions concerning each sector are described below.

---

* The analysis for the agricultural sector (Section 9) is a hybrid of a damage function and a market model.

The Household Sector (63.5%)--

In the household sector, it was determined that available data would allow development of a model incorporating the approach described previously. Recall that in this approach, the basic idea is that air pollution affects the implicit price of household activities such as "household operations". Higher levels of air pollution induce greater use of certain market goods, such as detergents, and thus lead to higher costs in carrying out household operations. Benefits are generated when reductions in air pollution reduce these implicit prices. Data were considered to be less adequate for consideration of demand shifting effects involving activities such as recreation.

In addition to the basic household sector analysis described above, two supplementary analyses were undertaken for this sector. One of the analyses examines property value differentials and the other examines wage rate differentials. The purpose of the two supplementary analyses is to provide a cross-check on the results from the basic household sector analysis. The basic analysis is reported in Section 4. The property value and wage analyses are reported in Sections 5 and 6 of the report, respectively.

The Government Sector (20.5%)--

The government sector on the final demand side includes the purchase of goods and services by all levels of government. To a lesser extent, the government sector also shows up on the producing

side and accounts for part of the "other" category in the previous figure.

During the course of the study, it was judged that an analysis for county and municipal governments might be feasible using the same basic approach as in the household sector analysis. It was decided, however, to postpone this analysis until the household sector model had been completed and the properties of that model were more well defined. As of this writing, the government sector analysis has not been initiated. Analysis of the Federal sector was considered to be somewhat more problematical. The additional difficulty in this case comes in identifying the location of Federal activities with respect to air quality conditions. No analysis of the Federal sector was therefore undertaken.

Agriculture, Forestry and Fisheries (3.1%)--

The constraining factor in conducting analyses of these sectors is the lack of air quality data in many rural areas. In particular, SO_2, which is the more important pollutant (compared to TSP) in terms of vegetation effects, is monitored in only about 10 percent of the counties in the U.S. This basically ruled out analysis of forestry and fisheries. For similar reasons, it was decided to limit the analysis of agriculture to a selected number of crops which met two criteria: (1) an economically significant amount of production occurs within or near metropolitan areas (and is thus more likely to be in areas where air quality is monitored); and (2) SO_2 is believed to have

damaging effects on that crop. Two crops which met these criteria were cotton and soybeans. The analysis for this sector thus focuses on these two crops.* The results are reported in Section 9 of this report.

Mining and Construction (7.1%)--

No analysis was undertaken for these sectors. In the case of mining, one serious constraint is that a considerable amount of mining occurs in remote areas where air quality data are limited. With construction, the problem is one of location variability. Except in the very largest construction projects, construction equipment is likely to be moved from one job site to another on a short-term basis so that matching of construction activity with air quality data would be problematical.

Manufacturing (23.9%)--

As in the case of the household sector, fairly extensive analyses of the economic characteristics of manufacturing industries have taken place and considerable manufacturing activity occurs in metropolitan areas where air quality monitoring is done. In view of these points and in view of the economic importance of the sector, it was decided that an analysis of this sector should be undertaken.

---

* Cotton and soybeans account for about 15 percent of the "value added" in the agriculture, forestry and fisheries industries. Thus, even though only two crops are considered in the study, they represent a significant fraction of the economic activity in these sectors. Value added is defined to be the value of production less the cost of raw materials.

Two difficult problems that were viewed as confronting the analysis were as follows: (1) The manufacturing sector is comprised of many hundreds of industries with widely differing processes. Available data sources generally provide either industry detail or geographic detail but are more limited when both kinds of detail are required. (2) Economic detail available is in relatively aggregate categories such as "labor" and "materials", with no breakdown into maintenance, operation, etc.

In view of the data constraints present in this sector, it was decided to limit the analysis to a few selected industries for which the available data were most complete. The basic analytical approach employed is the one described previously where an effort is made to identify whether there is a relationship between production costs and air quality not explainable by other factors. The results of this analysis are reported in Section 7 of the report.

Transportation, Communication and Utilities (9.0%)--

Analysis of air pollution effects on the transportation sector is difficult. This is because so much of the potentially affected material is in the form of rolling stock (e.g., airplanes and trucks) so that a matching of economic data to air quality data is generally not feasible. No analysis of this sector was therefore attempted.

Within the communications sector, the most economically significant industry is the telephone industry. As a regulated

industry, considerable data are available concerning telephone industry financial performance, physical plant, and output. A significant effort was therefore made to determine whether such data could be obtained for substate areas (e.g., exchanges) so that a matching with local air quality data would be possible. Contact with several individuals in the industry and the applicable regulatory agency indicated that data were not available at the geographic level required. No analysis of the communications sector was therefore undertaken.

Within the utilities sector, the largest industry is the electric utility industry. As a regulated industry, it is also well documented in terms of financial and physical characteristics. In particular, detailed cost and output data are available for individual generating plants so that a matching with air quality data is feasible. An analysis was therefore undertaken concerning the generation phase of the industry (transmission and distribution equipment are geographically dispersed so that an analysis of these phases was judged less feasible). The analytical approach was similar to that used for the manufacturing sector. In this case, however, available data made it possible to analyze the effect of air quality on maintenance cost as well as on total production costs. The results of this analysis are reported in Section 8. Analysis of the gas and sanitary utilities was not undertaken.

Commercial and Services (43.6%)--

The commercial and services sector is a mixture of industries including wholesale and retail trade; finance, insurance and real estate; and a wide variety of other service industries. Two approaches were initially considered for this sector, based on the assumption that soiling and aesthetic effects were dominant. One approach was to utilize data sources on maintenance activities by commercial cleaning companies to estimate maintenance costs for commercial buildings. The other was to look at commercial building rent or property value differentials in areas with differing concentrations of pollution. The latter approach is based on the same hypothesis as the residential property value technique in the household sector. Data sets along these lines were identified for certain areas of the country but were not fully adequate for developing national benefits estimates. No analyses were therefore undertaken in this sector.

Coverage of Sectors

The decisions concerning the basic scope of the study, as described in the previous section, are summarized in Table 2-1. The first and second columns in the table identify the sectors and the percent of economic activity accounted for by each sector. The third column indicates the percent of each sector covered by the basic analysis in each sector. For example, the basic analysis in the household sector covered 24 major metropolitan areas and a subset of

TABLE 2-1. COVERAGE OF ECONOMIC ACTIVITY IN EACH SECTOR

Final demand sector	Percent of final demand	Percent coverage	
		Basic analysis	Basic plus extrapolation
Households*	63.5	17	45-55
Government	20.5	0	0
Other	16.0	0	0
Totals	100.0	11**	29-35**

Producing sector	Percent of GNP	Percent coverage	
		Basic analysis	Basic plus extrapolation
Agriculture, forestry and fisheries	3.1	2-15	2-15
Mining and construction	7.1	0	0
Manufacturing	23.9	4-8	25-30
Transportation, communication and utilities	9.0	8-11	15-20
Commercial and services	43.6	0	0
Government and other	13.3	0	0
Totals	100.0	2-3**	7-9**

* Goods and services consumed by individuals and certain nonprofit institutions. Includes rental of dwellings but not purchases of dwellings. The latter are included with "other".

** Weighted average coverage.

Source: Estimates of final demand and GNP shares are from U.S. Department of Commerce, Bureau of Economic Analysis. Survey of Current Business. July 1979. Tables 1.1 and 6.1.

total consumption expenditures. This represented 17 percent of total activity in the sector. The agricultural sector analysis included two major crops representing 15 percent of activity in that sector. The manufacturing sector analysis covered six industries, accounting for 8 percent of that sector. The analysis of electric utilities focused on the generation phase which accounts for 11 percent of the transportation, communication and utilities sector. The table also provides subtotals of the coverage for the final demand sectors and the producing sectors.

In order to broaden the scope of the analysis, we made limited extrapolations of the results of the basic analysis. For example, the household sector analysis was extrapolated from the original 24 SMSAs to other areas of the country. No extrapolation was attempted in the agriculture sector. Results for the manufacturing sector were extrapolated to closely related industries. And data in the open literature were used to extend the electric utility sector results to include the transmission and distribution phases. The details of the extrapolation procedures are discussed in Section 10 of the report. The other pertinent report sections are also identified in the table.

It is important to note that this study does not provide complete coverage of all possible sectors. Nor does it include consideration of effects such as impacts on the ecosystem. In this respect, the benefits reported in the study are conservative estimates of the benefits of the secondary ambient air quality standards.

Validation of Results

A study of this type can have potentially important policy implications. Consequently, considerable effort was made to identify and incorporate methods for assessing the validity of the analytical results. The basic philosophy adopted was to build an information gathering process into the model development effort. This was done by identifying numerous checkpoints in the analyses where important information would be available. This information could then be used both to assess the plausibility of the results at that stage and to guide model development at the next stage. Although there were some variations in the validation procedures used in each sector, the validation procedures generally included in each sector analysis were of the types summarized below.

Statistical Tests--

All of the sector models incorporate mathematical equations whose coefficients have been statistically estimated. A key advantage of this approach is that it allows formal tests of the structure and contents of the models. In particular, standard tests can be used to assess: the importance of particular variables, the importance of interactions between variables, the overall explanatory power of the models, and the error properties of the models. These tests can thus be used both to guide model development as well as to assess the analytical results.

Economic Tests--

All of the sector analyses are based on economic models. The sector models are generically similar to ones developed by other researchers for a variety of other purposes. Consequently, the basic economic properties of the sector models can be examined to determine whether they are consistent with economic theory and with other results in the open literature. Clearly, if the sector models do not measure up in terms of their basic economic properties, then one would have little confidence in their ability to measure air pollution effects. Depending on the sector, the economic properties which provide a basis for assessment and comparison include such properties as the magnitudes and signs of the price elasticities of demand, and the magnitudes and signs of the elasticities of substitution.*

Sensitivity Tests--

In any model development effort, an important consideration is the possible sensitivity of the results to the methods, data and assumptions used. In an effort to judge the robustness of the estimated sector models, a variety of sensitivity tests were undertaken. Depending on the particular sector, these tests included: varying the functional form of the equations, varying the ways in which pollution variables enter the equations, using alternative measures of pollution, and re-estimating the equations over different subsamples of the data.

---

* Definitions of these parameters are provided in the individual sector reports.

Plausibility Checks--

Each of the sector models is designed to predict the economic effect of a change in air pollution. It is thus possible to compare the economic effect of air pollution, implied by the models, with other economic characteristics of the sectors. Clearly, for example, one would expect the economic effect on a household to be much smaller than household income. Similarly, the effect on an industry or farm should be much smaller than their other economic costs.

One can also ask whether there is existing physical evidence to support or reject the finding of an economic effect from air pollution. This can range from asking firms whether they have a problem with atmospheric corrosion, to identifying whether the implied alteration in household expenditure patterns is consistent with physical effects identified in the open literature.

Comparison of Benefits Estimates--

There have been a variety of previous studies which have developed estimates of the benefits of air quality improvements. Unfortunately, there is wide variation among these studies in the methods used, the time periods covered, the measures of pollution, and the assumed changes in air quality. As a result, we found it difficult to compare the aggregate benefits we estimated in each of the sectors with estimates from the earlier studies. Comparisons were particularly difficult with the manufacturing and electric utility sectors, and to a lesser extent in the other sectors.

In the household sector analysis, it was possible to develop gross comparisons of estimated benefits in a different way. As indicated previously, the basic model for the household sector analyzes household expenditure variations to develop benefits estimates. Independent estimates for the household sector were also developed as part of this study, based on the residential property value and labor wage rate techniques described previously. These three analyses are reported in Sections 4, 5, and 6 of this report.

REFERENCES

1. Mishan, E. J. Cost-Benefit Analysis (2nd Edition). Praeger, New York, 1976.

2. Baumol, William J. and Wallace E. Oates. The Theory of Environmental Policy. Prentice-Hall, Englewood Cliffs, New Jersey, 1975.

3. Crocker, Thomas D., et al. Methods Development for Assessing Tradeoffs in Environmental Management (4 Vols.). Final report under EPA Grant R805059010. Laramie, Wyoming, 1978.

4. Freeman, A. Myrick, III. The Benefits of Environmental Improvement: Theory and Practice. Johns Hopkins University Press, Baltimore, Maryland, 1979.

5. Mäler, Karl-Göran. Environmental Economics: A Theoretical Inquiry. Johns Hopkins University Press, Baltimore, Maryland, 1974.

6. Smith, V. Kerry. The Economic Consequences of Air Pollution. Ballinger Publishing Company, Cambridge, Massachusetts, 1976.

7. Fink, F. W., F. H. Buttner and W. K. Boyd. Technical-Economic Evaluation of Air Pollution Corrosion Costs on Metals in the U.S. (NTIS: PB 198 453). Battelle Memorial Institute, Columbus, Ohio, 1971.

8. Salmon, R. L. Systems Analysis of the Effects of Air Pollution on Materials. Midwest Research Institute, Kansas City, Missouri, 1970.

9. Ryan, John W., et al. An Estimate of the Nonhealth Benefits of Meeting the Secondary National Ambient Air Quality Standards. Final report prepared for the National Commission on Air Quality, SRI International, Menlo Park, California, 1981.

10. Willig, Robert D. Consumers' Surplus Without Apology. American Economic Review, 66:589-597, 1976.

11. Randall, Alan and John R. Stoll. Consumer's Surplus in Commodity Space. American Economic Review, 70:449-455, 1980.

12. Schmalensee, Richard. Another Look at the Social Valuation of Input Price Changes. American Economic Review, 66:239-243, 1976.

13. Anderson, Robert J., Jr., et al. Quantifying the Benefits to the National Economy from Secondary Applications of NASA Technology. NASA Contract NASW-2734, Mathematica, Inc., Princeton, New Jersey, 1975. The extension involved the assumption of linear demand functions in each final good market.

14. Just, Richard E. and Darrell L. Hueth. Welfare Measures in a Multimarket Framework. American Economic Review, 69:947-954, December 1979.

15. See, for example, Freeman, op. cit. pp. 72-75.

16. U.S. Department of Commerce, Bureau of Economic Analysis. Survey of Current Business. Vol. 59, July 1979. Tables 1.1 and 6.1.

SECTION 3

AIR QUALITY AND METEOROLOGICAL DATA

SECTION 3

AIR QUALITY AND METEOROLOGICAL DATA

INTRODUCTION

This section describes the procedures that were used in constructing the air quality/meteorological data base. Air quality data were supplied by the U.S. Environmental Protection Agency from the SAROAD data file maintained by the Agency. Meteorological data were collected from various issues of the U.S. National Oceanic and Atmospheric Administration's Local Climatological Data series.

The section is divided into two major parts. Initially, we discuss the air quality data used in the analysis. The presentation describes specific attributes of the air quality data, the temporal and spatial scope of the data, and various transformations which were required in order to bring the data into a useable form. Following our discussion of the air quality data, we outline the meteorological data available for the study.

AIR QUALITY DATA

Air quality data were obtained on ambient concentrations of sulfur dioxide (SO_2) and total suspended particulates (TSP) on an annual basis for the years 1972-78, inclusive, while quarterly data

were supplied for SO_2, TSP, total oxidants, and ozone over the same time span. A variety of pollutant measurement techniques, averaging times, and pollutant measurement indices (e.g., arithmetic mean, geometric mean) were obtained. Site identification codes as well as county, SMSA, and state codes were included with each data record.* This diversity of location identifiers provided flexibility with respect to defining the spatial unit of observation.

The spatial coverage of the air quality data was, of course, limited by the placement of monitoring stations. Furthermore, only those monitoring sites meeting summary criteria established by EPA were included in the data file. The summary criteria represent minimum data collection requirements for individual sites, and statistics such as the annual arithmetic mean are reported for only those sites satisfying these criteria. The summary criteria are defined in Reference (1) as follows:

- Criteria for continuous observations with sampling intervals less than 24 hours are:
  - Data representing quarterly (annual) periods must reflect a minimum of 75 percent of the total number of possible observations for the applicable quarter (year).

---

* It should be noted that SMSA definitions are revised periodically, and thus the SMSA codes reported in the SAROAD data base may vary depending on when the codes were assigned. If the geographic unit of observation is to be an SMSA, we would advise others using the SAROAD data to aggregate to the SMSA level from the counties that make up the SMSA.

- Criteria for noncontinuous observations with sampling intervals of 24 hours or greater are:

  -- Data representing quarterly periods must reflect a minimum of five observations for the applicable quarter. Should there be no measurements in one of the three months of the quarter, each remaining month must have no less than two observations reported for the applicable period.

  -- Data representing annual periods must reflect four quarters of observation that have satisfied the quarterly criteria.

With these constraints, the geographic range of sites was limited. For example, in 1978 there were 3,042 counties in the United States (2), yet valid TSP data were available for only 1,000 counties and SO_2 data were limited to 182 counties. The coverage is even less when other pollutants such as oxidants are considered.*

These restrictions on air quality data availability have implications for both the estimation phase and the benefits calculation phase of the analysis. In the estimation phase, economic data may be available for a location for which there is no air quality data. In this case, potential observations would be lost unless the "missing data" problem can be overcome. Further discussion of ways in which the "missing data" problem was handled is presented within each of the sector analyses.

---

* There does exist an ancillary air quality data set of "design values" which provides more extensive geographical coverage of counties. However, certain assumptions used in the construction of the design values were felt not to be appropriate for the statistical estimation phase of this study.

With respect to the benefits calculation phase, the absence of a complete set of air quality data implies that only a partial estimate of national benefits can be derived. However, this would not be true if data were available for all sites which exceed the secondary standards. Although we cannot confirm that this is the case, it seems reasonable to assume that monitoring sites would be located in those areas that were believed to have high concentrations of various pollutants. In this case, reasonable coverage of the geographic dispersion of national benefits would be expected.

Air quality concentrations vary not only across locations, but also across time. For example, analysts of air pollution data have noted that there are diurnal cycles, weekend/weekday cycles, seasonal patterns, and year-to-year trends. In an assessment of air pollution effects, these time-dependent variations must be taken into account. Thus, in the analysis of agricultural benefits, quarterly data were used in order to better characterize the exposures faced by crops during their growing period. In the other sectors, where the primary concern was with soiling and materials damage estimates, annual data were employed. This choice appeared reasonable given the exposure durations typically associated with these effects, but it was also conditioned by the fact that the available economic data in these other sectors were reported on an annual basis.

In addition to the cyclic variations in observed pollution patterns, one must also be concerned with the averaging times used to

present summary information of air quality levels. The averaging time represents the period over which air quality concentrations are observed before an index is developed. The shorter the averaging time, the more variation there will be in the data for a fixed period of observation. For example, in the course of one year, a graph of one-hour averaging time concentrations could have as many as 8,760 observations, while a graph of 24-hour averaging time concentrations would record at most 365 data points (which are averages of the 24 one-hour observations for each day).

Averaging times become important in characterizing the possible damaging effects of pollution. For example, it is believed that damage to vegetation can occur with a single exposure to high concentrations of, say, SO_2. This implies that one would want a measure of maximum concentrations occurring for fairly short averaging times. Conversely, metal corrosion occurs over a long time period of continued exposure so that an average based on longer averaging times would be more appropriate. These considerations have been taken into account by the developers of measurement instrumentation, so that the form of the data when it is collected is typically recorded in an averaging time that is reasonable for analyses involving the particular pollutant. Because of this, we have made no adjustments to obtain averaging times that do not appear in the SAROAD data file.

In the analysis phase of the study, air pollution data were merged with economic data of the same year. In particular, no lag

structure was introduced into the analysis. This implies that current air quality levels serve as a proxy for the historical levels of air quality in an area. Specific details on how the air quality data were used in the analysis and benefits calculations appear in each of the sector discussions.

There are several other general attributes of the air quality data which are important for defining the scope of the analysis. First, the data obtained are for recorded ambient concentrations of air pollutants. In particular, the data are generated from discrete receptors and not derived from an analysis of emission dispersion characteristics. Thus, the implied exposure patterns imperfectly reflect exposure experiences of individual economic units. However, since our economic data typically represent only the behavior of the average (or representative) economic unit for a geographical area (e.g., a county), aggregation of site-specific air quality data across an equivalently defined region would permit the definition of the corresponding representative exposure levels for that area. More detailed discussion of the spatial aggregation procedures used in this study is provided in the reviews of the specific pollutants.

Finally, no distinction is made between ambient concentrations and indoor pollution levels (self-generated or otherwise). The ambient concentrations are viewed as proxies for the actual exposure concentrations and any damaging effects which may accompany a particular level of exposure.

In the remaining parts of this discussion of the air quality data, the specific attributes of the various pollutants included in this study are examined more closely. Particular emphasis is placed on reviewing various data transformations which were required in order to bring the data into a useable form.

Total Suspended Particulates (TSP)

The reference measurement technique for TSP is the Hi-Volume Gravimetric, 24-hour averaging time method, with concentration levels reported in $\mu g/m^3$. This methodology is the only method observed on the SAROAD data tape. Because of this, no additional effort was required to ensure that data compatibility was maintained.

Spatial Aggregation--

In the estimation phase of the analysis, the major effort of data manipulation involved spatial aggregation procedures. Since the unit of analysis in our economic data is a geographic area defined by political boundaries (e.g., a county), exposure patterns can vary substantially within a given area. This implies that a single-number pollutant index for the area must be viewed as only an approximation to the actual exposures experienced by individual economic units. Freeman (3) provides a concise description of the biases that may arise when such spatial aggregation procedures are employed. While we recognize the possibility of bias in a single-number index, the

aggregate nature of available economic data makes more sophisticated, multiple index procedures such as isopleth mapping impractical.

The aggregation procedures used were as follows. For each site within a county, data for the annual geometric mean and the second highest annual reading were obtained. For both of these measures, the arithmetic mean was calculated across all sites in the county. This procedure yielded the county average of the annual geometric mean and second-high readings. The second method used in defining a county index for TSP involved finding the maximum reading from among all sites in the county for the geometric mean and the second highest concentrations. Thus, for each county, there were four separate indices that could be used. For example, assume that four sites exist in a particular county with annual geometric means of 40, 70, 50, and 40 and 24-hour second-high observations of 200, 380, 400, and 240. Then the four indices would have the values:

- Average annual geometric mean equals 50 $\mu g/m^3$.
- Maximum annual geometric mean equals 70 $\mu g/m^3$.
- Average second high equals 305 $\mu g/m^3$.
- Maximum second high equals 400 $\mu g/m^3$.

Note that when an SMSA was the unit of observation, similar aggregation procedures were used. In particular, the county average and maximum indices were aggregated to obtain the SMSA average and maximum geometric mean and second-high indices.

Air Quality Standards--

The use of the geometric mean and the second highest observed concentration level was conditioned by the units of the air quality standards. Table 3-1 lists the Federal primary and secondary national ambient air quality standards that are currently in force for TSP. Note that the annual secondary standard of 60 $\mu g/m^3$ is only a guide for assessing State Implementation Plan achievement of the legislated 24-hour secondary standard of 150 $\mu g/m^3$. It is important for our analysis that both a primary and a secondary standard are defined, since the benefits estimated are those that would accrue with a change from the primary to a secondary standard. While this causes few problems with TSP, complications do arise when SO_2 is considered.

TABLE 3-1. NATIONAL AMBIENT AIR QUALITY STANDARDS FOR PARTICULATE MATTER

Averaging time	Primary standards	Secondary standards
Annual (geometric mean)	75 $\mu g/m^3$	60 $\mu g/m^3$*
24-hour**	260 $\mu g/m^3$	150 $\mu g/m^3$

* To be used as a guide for assessing State Implementation Plan achievement of the 24-hour secondary standard.

** Not to be exceeded more than one per year.

Source: Air Quality Data -- 1977 Annual Statistics.

Temporal Aggregation--

As noted earlier, air quality varies not only spatially but also temporally. Exposures can vary dramatically on a fairly short-term basis, so that a summary measure of the time path profile of exposure patterns can be sensitive to the averaging time used to characterize the temporal aspects of pollutant concentrations. The standards for TSP have been set on the basis of a 24-hour filter sample, which is appropriate for identifying longer-term effects of TSP (e.g., weekly, monthly, or annual cycles). Since TSP is primarily associated with soiling and materials damage effects, the longer averaging times appear to be reasonable characterizations of the relevant time profile. We have made no changes in the reported TSP data to account for other averaging times.

Benefits Calculations--

TSP data are also used in the calculation of benefits. As was described in Section 2, benefits can be identified by examining changes in cost or demand functions before and after a specified change in air quality. For the most part, this process is straightforward. One simply evaluates and compares the economic functions at the different levels of air quality, where the units (e.g., averaging time) of the air quality measures are consistent with those used in the estimation phase of the analysis. Thus, if a demand function is estimated which depends on the 24-hour second-high concentration of TSP, benefits would be calculated for the achievement of the 24-hour secondary standard of 150 $\mu g/m^3$. Ostensibly, the

annual primary and secondary TSP standards have no place in the calculation of benefits. However, this is not necessarily the case. Consider the following example.

Assume that TSP concentrations in a particular county are at levels that violate either of the two primary standards. Since the benefits estimates derived in this analysis are conditional on the attainment of the primary standard, TSP levels in the county must be reduced to the primary standard prior to the calculation of benefits. But which of the primary standards is to be chosen? If the analysis leading to the evaluation of benefits is done in terms of the second-high concentrations, then the 260 $\mu g/m^3$ standard would appear to be appropriate. However, this choice neglects the fact that the annual primary standard may be more stringent so that additional improvements in TSP levels must be made if both standards are to be met. If the annual standard is more stringent, then it becomes the "controlling standard" since it imposes the binding constraint on acceptable ambient concentrations of TSP. This means that when the annual primary standard is met, the expected 24-hour second-high ambient concentration levels would be less than the primary standard levels of 260 $\mu g/m^3$. Consequently, even though the analysis is in terms of second-high concentrations, evaluation of benefits from the primary standard of 260 $\mu g/m^3$ to the secondary standard of 150 $\mu g/m^3$ would lead to an overestimate of benefits.

In going from the example posed above to real data, several questions arise. Is the annual standard ever the controlling standard? If it is, how can one identify the expected second-high concentrations that would be consistent with attainment of the annual primary standard? For both questions, the answer requires the ability to express concentration levels in different averaging times. Formulas for the desired transformations have been developed by Larsen (4) under the assumption that pollutant concentrations are distributed log normally. The use of the formulas requires information on concentration levels and the standard geometric deviation (SGD). The SGD is defined by Larsen as:

$$SGD = \exp\left[\frac{\Sigma(\ln C - \ln M_g)^2}{n}\right]^{1/2} \qquad (3.1)$$

where C is the level of concentrations

M_g is the geometric mean

n is the number of observations

ln is the natural log (base e) function

exp is the exponential function.

Table 12 in Larsen (4) indicates that when the SGD is less than 1.53, the annual primary standard for TSP will be the controlling standard. A review of our data reveals that this is the case in approximately 20 percent of site observations. However, it should be noted that the reported SGD is for current levels of TSP, while the

SGD that should be used is that which would occur after the less stringent standard has been achieved. Unfortunately, this measure is not observed, and it is difficult to judge whether the observed SGD is likely to be greater, less than, or equal to the SGD that would occur if the second-high standard is attained. Because of this, any computation of the expected second-high concentrations must assume an explicit value for the SGD.

The actual computation of the expected second-high concentration level, given that the "controlling" annual primary standard is achieved, can be derived from Equations (13) and (72) in Larsen (4), and presented here as Equations (3.2) and (3.3).

$$\ln M = \ln M_g + 0.5 \ln^2 SGD \qquad (3.2)$$

$$M = C(SGD)^{(0.5 \ln SGD) - Z} \qquad (3.3)$$

where M is the arithmetic mean

Z is the number of standard deviations between a particular frequency and the median, and the other terms are as previously defined.

With the variables in Equations (3.2) and (3.3) being site-specific, each of the several sites within a county or SMSA may have a different starting point for benefits calculations. Since our benefits estimates are derived at the county or SMSA level, there is some question as to the concentration level at which to begin the

benefits evaluation. Several options are available. An average of the "effective" 24-hour second-high standards for each site could be evaluated, minimums or maximums from among the sites could be used, or one could simply adopt the alternative secondary standard value of 260 $\mu g/m^3$. Ultimately, it was decided to use the alternative second-high standard in this study. As noted earlier, this leads to a slight overestimate of benefits. The principle reason for adopting this assumption was the realization that our estimates of exposure patterns were approximations, and that the refinements suggested above would likely give a false sense of precision to the numbers being used. However, it was felt to be important to point out this particular problem since we were not aware that other benefits analysts had explicitly considered it.

Summary of TSP Data--

This completes our review of the TSP data available for the study. Overall, it is our opinion that the data are acceptable. Spatial availability is widespread and the fact that one pollutant methodology is (and has been) dominant makes working with the data straightforward. This is in contrast to our experience with SO_2, where several challenging problems had to be overcome before the data were acceptable for the benefits analysis.

Sulfur Dioxide (SO_2)

The construction of a data file for SO_2 was complicated by several factors. These included:

- The spatial coverage of SO_2 monitoring stations was limited.
- Different methodologies were used to measure SO_2 levels in the 1970's.
- Current air quality standards do not include both primary and secondary standards of the same averaging time.

Before we discuss these specific problem areas, we will briefly review the general characteristics of the available data and the SO_2 air quality standards used in the calculation of benefits.

Air Quality Standards--

The regulatory standards for SO_2 have changed in the past decade. The current Federal primary and secondary standards are listed in Table 3-2. One feature of the table that is important for our analysis is that the averaging times differ for the primary standards and the secondary standards. Since our benefit evaluations involve movement between the two standards, some method must be devised to find "equivalent" standards in different averaging times. For example, we would want to find out what the expected second-high 24-hour averaging time concentration would be given that the second-high 3-hour averaging time standard of 1,300 $\mu g/m^3$ was just met. The

TABLE 3-2. NATIONAL AMBIENT AIR QUALITY STANDARDS FOR SULFUR DIOXIDE

Averaging time	Primary standards	Secondary standards
Annual (arithmetic mean)	80 $\mu g/m^3$	--
24-hour*	365 $\mu g/m^3$	--
3-hour*	--	1,300 $\mu g/m^3$

* Not to be exceeded more than once per year.

Source: Air Quality Data -- 1977 Annual Statistics.

expected 24-hour second-high value could then serve as a pseudo-standard. This topic will be discussed more fully below.

The fact that the only SO_2 secondary standard that is currently part of Federal regulation is a 3-hour averaging time standard concerned us. Discussions with EPA personnel confirmed what we suspected. The 3-hour standard was set on the basis of observed vegetation damage. Because most of our sector analyses deal primarily with soiling and materials damage effects, we believed that it was more appropriate to look at alternative standards that are expressed in longer averaging times. In fact, in the early 1970's, such standards did exist. This expanded list of SO_2 standards is presented in Table 3-3. In our sector analyses, benefits estimates are provided for both the attainment of the "equivalent" pseudo-standard and the alternative secondary standards shown in Table 3-3.

TABLE 3-3. AN ALTERNATIVE SET OF AMBIENT AIR QUALITY STANDARDS FOR SULFUR DIOXIDE

Averaging time	Primary standards	Secondary standards
Annual (arithmetic mean)	80 $\mu g/m^3$	60 $\mu g/m^3$
24-hour*	365 $\mu g/m^3$	260 $\mu g/m^3$
3-hour*	--	1,300 $\mu g/m^3$

* Not to be exceeded more than once per year.

Spatial and Temporal Considerations--

The various procedures described for the spatial aggregation of TSP data were followed with SO_2. In particular, for each county or SMSA, four indices of SO_2 concentrations were developed. These included the average and maximum arithmetic means, and the average and maximum second-high concentration levels. Note that the units of these indices are consistent with the units of the SO_2 primary and secondary standards. As with TSP, the county averages and maximum values were obtained by looking across sites, while SMSA indices were derived from the estimated county statistics.

Although the existence of the 3-hour averaging time secondary standard implies that average and maximum second-high values should be calculated for this averaging time, this was not done. Each of our

sector analyses relies on indices generated for the annual arithmetic mean or the 24-hour second-high readings.*

While the general approach to developing an SO_2 data file was the same as the used for TSP, the problems mentioned at the beginning of this subsection required us to consider making several transformations in the raw data.

Limited Scope of Data--

No matter which pollutant measurement methodology is considered, there does not appear to be a single year in which there are more than a couple of hundred counties for which valid (i.e., meet the summary criteria) SO_2 statistics are available. This compares with the over 3,000 counties in the United States. Naturally, if the counties for which data are available represent all counties that have anything more than background concentrations of SO_2, then no problem exists for the benefits calculation part of the analysis. However, in the analysis of the economic relationships, the absence of a large number of counties with SO_2 data severely constrains the number of observations available for inclusion in the study.

One possible solution to this problem was to use a set of air quality "design values" that have been developed. These design values use the SAROAD data as a base, but augment the SAROAD values through

---

* Note that the arithmetic mean is the same for all averaging times.

county-by-county adjustments after a review of records and consultations with local and regional air quality officials. With this method, over 700 counties had data available in 1978, versus 182 with the unaltered SAROAD data file.

There were several problems, however, with using the design values. In the economic analysis phase, we felt that it was important for the air quality data to be drawn from the same year as the behavioral data. The design values are defined as maximum values that occur over a several-year period. This feature made them unattractive for the economic analysis. On the other hand, characterizing county pollution levels from data taken across several years made some sense for the calculation of benefits. Consideration of several years might give a better picture of what the long-term pattern of air pollution is like in a given county. Unfortunately, because the design values represent aggregate indices, it is not possible to recover site-specific measures of the standard geometric deviation. Consequently, it would not be possible to transform data of one averaging time to another. Given these problems, we felt that it was more appropriate to use only the SAROAD data base. A discussion of how the limited observations affected the economic analysis is presented in each of the sector discussions.

Different Pollutant Measurement Methodologies--

In the early 1970's, the dominant method for measuring SO_2 pollutant concentrations was the noncontinuous "gas bubbler"

technique. As technical advances were made in instrumentation throughout the decade, continuous methods became the principal measurement methodology. Normally, if both methodologies provide an accurate measure of ambient concentrations, then no compatibility problems would exist and observations from the different methodologies could be used together.

However, it has been shown that data derived from the gas bubbler methodology is biased. In particular, the integrity of a sample collected by the gas bubbler method is dependent on temperature. Up to 50 percent of the sample can be "lost" if various steps in the sampling process are not temperature controlled. This potential bias does not appear to exist with the continuous monitoring methods.

One obvious solution to this problem would be to discard concentrations generated from the gas bubbler measurement technique. This was not practical since much of our economic data was available only for the early 1970's. During this time period, if only continuous data were used, the number of observations available for analysis would fall to unacceptable levels.

Because the bias was identified with a temperature dependency, another approach to overcoming the problem would be to develop a relationship between concentrations recorded by the continuous methods and concentrations recorded by the gas bubbler technique at the same

site, for the same time period, and with temperature included in the expression.

A data set was put together for 28 sites across the United States that monitored SO_2 with both methodologies in 1977. All sites included in the data set met the summary criteria for reporting annual means.

A functional relationship between the concentrations of the two pollutant measurement methodologies was developed by regression analysis. Several specifications were tried, and the "best" (by a criteria of highest R^2) are reported as Equations (3.4) and (3.5). The regression for the annual mean uses annual data, while the second-high regression uses quarterly data.

$$\underset{}{\text{AMCONT}} = \underset{(5.222)}{19.0034} + \underset{(5.584)}{1.61875}\ \text{AMGAS} - \underset{(-1.828)}{0.05756} \cdot (\text{AMGAS} \cdot \text{TEMP}) \qquad (3.4)$$

$$\underset{}{\text{SECHICONT}} = \underset{(2.621)}{42.621} + \underset{(8.875)}{2.0612} \cdot \text{SECHIGAS} + \underset{(1.994)}{0.033642} \cdot (\text{SECHIGAS} \cdot \text{TEMP}) \qquad (3.5)$$

where AMCONT is the annual arithmetic mean measured by the continuous method in $\mu g/m^3$.

AMGAS is the annual arithmetic mean measured by the gas bubbler method in $\mu g/m^3$.

TEMP is the average annual temperature in degrees Celsius.

SECHICONT is the second highest reading recorded by the continuous monitors.

SECHIGAS is the second highest reading recorded by the gas bubbler method.

In Equation (3.4), the R^2 is 0.802, while the R^2 is 0.497 in Equation (3.5). The numbers in parentheses are t-statistics.

The interpretation of this relationship is that expected continuous readings can be predicted by observing gas bubbler concentrations and temperature. The interaction term of TEMP with AMGAS and SECHIGAS allows the level of TEMP to influence marginal changes in measured concentration levels. Note that the sign on the interaction term is negative in Equation (3.4) and positive in Equation (3.5). A priori, a positive sign is expected since the gas bubbler data are biased downward with increasing temperature. The negative sign in Equation (3.4) may be due to the small sample used in the analysis. In any case, in the subsequent sections of this report, statistically significant air pollution impacts were found only in those instances where second high data were used. While it is plausible that second high measures represent the proper index for air quality data in the economic relationships, the fact that annual data were not statistically significant may be a reflection of the poorly specified nature of Equation (3.4).

Since all of the data used in estimating Equations (3.4) and (3.5) are from 1977, the assumption is that this same relationship would hold in earlier years of the 1970's, and that gas bubbler data can be "corrected" to an unbiased measure of concentrations. Data for 1977 were used because earlier years had few sites monitoring with both methodologies.

In the economic analysis phase of the study, these equations were used to convert gas bubbler data prior to estimation.* It should be noted, however, that the 1978 data which served as our base year in the benefits calculations consisted of only the unbiased instrumental data. Thus, no conversions were required.

Averaging Times and Air Quality Standards--

The final problem to consider involves the fact that current Federal primary and secondary standards for SO_2 are defined for different averaging times. In particular, the primary standards are stated in terms of an annual arithmetic average and a 24-hour second high, while the secondary standard is a 3-hour second-high standard. If we are to determine the economic benefits associated with an improvement in air quality from a primary to a secondary standard, then it must be possible to express both standards in an equivalent averaging time.

---

* In the agricultural sector, the data used in the analysis were quarterly and separate conversion equations were estimated in this sector. See Section 9.

There are two ways of looking at this problem. First, one could attempt to define the 3-hour averaging time concentration level that would be expected to occur when the 24-hour averaging time primary standard was just met. This expected concentration level could then serve as a pseudo-primary standard. Alternatively, one could attempt to define the 24-hour averaging time concentration level that would be expected to occur when the 3-hour averaging time standard was attained.* In either case, a relationship must be developed between concentrations of one averaging time and those of a different averaging time.

The same type of problem was encountered in our discussion of the TSP data file. There, we noted that Larsen (4) has developed sets of equations that relate parameters of different averaging times. These relationships are established by assuming that concentration levels are log-normally distributed for all averaging times. Use of the equations developed by Larsen requires information on concentration levels and the standard geometric deviation (SGD), which was defined in our discussion of the TSP data.

The transformation we have elected to use involves finding the 24-hour averaging time concentration that would be expected to occur given the SGD of the site and assuming that the 3-hour standard of 1,300 $\mu g/m^3$ is just met. This expected concentration level could then

---

* A similar relationship could be considered between the annual arithmetic mean and the 3-hour secondary standard.

serve as a pseudo-secondary standard which could be compared directly to the 24-hour second-high primary standard.

The relationship we use to obtain this value is a version of Larsen's equation (71). However, instead of solving for SGD, we want to solve for the expected 24-hour concentration level. After a rearrangement of terms, Larsen's equation can be written as:

$$\ln C_{24} = 0.175 \ln^2 SGD - 1.1615 \ln SGD + \ln(1,300) \quad (3.6)$$

where $\ln C_{24}$ is the natural log of 24-hour averaging time concentration levels.

SGD is the standard geometric deviation for a 24-hour period.

For typical values of SGD, Equation (3.6) yields values of C_{24} that are mostly in excess of the current 24-hour primary standard. For example, with SGD equal to 3.0, C_{24} is found to be 448 $\mu g/m^3$. Since the primary standard is 365 $\mu g/m^3$, and we assume that the primary standard is met, there would be no benefits associated with attaining a pseudo-secondary standard that reflected air quality levels consistent with attainment of the 3-hour standard. This observation is in accord with conclusions reached by Larsen. He notes that except in areas with strong, high sources of sulfur dioxide, standards based solely on 24 averaging time concentrations would be expected to control source reduction plans. This is borne out in our data since only five counties in the United States have an expected

pseudo-standard less than the current primary standard. Although the number of counties is small, benefits estimates are reported for these counties in the sector analyses. The benefit numbers presented in these analyses represent our estimates of the benefits that would be achieved through attainment of the current 3-hour standard.

There was concern on our part as to the appropriateness of the 3-hour secondary standard for SO_2. As we noted earlier, the relatively short averaging time reflects concern for items such as vegetation that may be damaged by high short-term concentrations. Given that many of our sector analyses focus on soiling and materials damage effects, a standard defined for a longer averaging time may provide a more appropriate basis for evaluating benefits of air quality improvements. Consequently, we have also estimated the economic benefits that would be realized by attainment of an alternate secondary standard of 260 $\mu g/m^3$. This standard is stated in terms of a 24-hour averaging time second high and can be compared directly to the current primary standard of 365 $\mu g/m^3$. Although the concentration level of 260 $\mu g/m^3$ is somewhat arbitrary, this number has been used in the past as a guide in assessing implementation plan achievement of the secondary standard.

Summary of SO_2 Data--

In its raw form, the SO_2 data available from the SAROAD data base have several shortcomings. In this subsection, we have outlined the procedures that were used to overcome these obstacles. While the SO_2

data do not approach the completeness of the TSP data, we do believe that what is available is adequate for deriving reasonable benefits estimates.

Other Pollutants

Although only TSP and SO_2 concentrations were used in the analyses reported in this study, air quality data for total oxidants and ozone were also obtained. Originally, our intent was to include these pollutants in the model developed for the agricultural sector, since evidence exists that the principle damaging agent for many crops is ozone. Unfortunately, the geographical scope of ozone data is so limited that available observations were reduced to unacceptable levels. Consequently, in the final specifications of the various sectors, no pollutants other than SO_2 and TSP have been included.

METEOROLOGICAL DATA

The Criteria Document summarizes several studies which have reported an interrelationship between meteorological variables and the damaging effects of air pollutants. For example, Schwarz (5) reports that the corrosion rate of a metal can be expected to increase by 20 percent for each increase of one percent in relative humidity above a critical level, while Setterstrom and Zimmerman (6) find that plant sensitivity increases with higher levels of relative humidity. Other climatological variables may also be important. Temperature,

rainfall, wind speed, and exposure to sunlight all have been shown to have varying degrees of influence on the extent to which ambient concentrations of various pollutants can be expected to promote damaging effects.

The implication of these observations is that it may not be correct to draw inferences about damages or responses of economic units to alternative levels of concentrations without giving consideration to the possible interactive influence of exogenous meteorological variables. In effect, these other factors should be controlled for by including measures of them in the model specifications. Even more importantly, these other factors may also have direct effects on economic units, independent of pollution. For example, temperature and rainfall may influence agricultural yields directly, as well as influencing the effect of pollution variables.

To this end, data were collected from various issues of the National Oceanic and Atmospheric Administration's Local Climatological Data Series. Two separate data files were created. First, data were obtained from the 1972-1974 annual summaries of climatological data. These summaries provide statistics for approximately 250 urban areas in the continental United States. The data coded for the present study included the following variables:

- Average annual temperature in degrees Celsius.
- Total annual precipitation in millimeters.

- Average percent relative humidity at 7 a.m. and 1 p.m.
- Average annual wind speed in meters per second.
- An index of average sky cover.

These data are typically reported for one weather station within a given area so that no spatial aggregation is required. In those instances where more than one weather station in an area was included in the annual summaries, data from only the urban reporting station were coded. No additional transformations to these data were undertaken.

Despite the variety of weather parameters available in the annual summaries, there were several drawbacks to the data which necessitated an additional data collection effort. Specifically, the annual nature of the data made it inappropriate for the agricultural sector analysis since crop and air quality data from the second quarter were used in that part of the study. In addition, the geographic scope of the annual data was limited. Typically, data were available only for counties which included fairly large urban areas. This placed a restriction on the number of observations available for the analysis. In order to overcome these difficulties, additional climatological data were collected from various yearly State volumes of weather data. These publications include daily accounts of weather patterns for all the weather stations across the United States. Since this is an extensive network, spatial coverage was very good. In fact, most counties have multiple reporting stations. However, because these

data were hand-coded, only a single station was chosen for each county, with the choice based on the centrality of the site with respect to county boundaries.

The advantage of detailed spatial coverage was offset by the fact that most weather stations report only temperature and precipitation. In fact, it appears that only those areas included in the annual summaries record parameters other than these two standard indicators of climate. Consequently, much of our analyses were limited to consideration of temperature and precipitation.

In the construction of this second meteorological data file, the decision of which counties to code was guided by the availability of other data. In particular, since the air quality data tended to be the limiting factor, in general, temperature and precipitation data files were put together only for those counties with valid air quality data.

REFERENCES

1. U.S. Environmental Protection Agency. Air Quality Data - 1977 Annual Statistics.

2. U.S. Department of Commerce. Statistical Abstract of the United States, 1978.

3. Freeman, A. M. The Benefits of Environmental Improvement. Johns Hopkins University Press, Baltimore, 1979.

4. Larsen, R. I. A Mathematical Model for Relating Air Quality Measurements to Air Quality Standards. U.S. Environmental Protection Agency, Office of Air Programs Publication AP-89, November 1971.

5. Schwarz, H. Uber die Wirkung des Magetits beim Atmospherischen Rosten und beim Unterrosten von Austrichen. Werkst, Korros, 23:648-663, 1972.

6. Setterstrom, C. and P. Zimmerman. Factors Influencing Susceptability of Plants to Sulphur Dioxide Injury. Contrib. Boyce Thompson Inst., 10:155-186, 1939.